ENGINEERING GEOLOGY FIELD MANUAL

I 27.19/2:

ENGINEERING GEOLOGY FIELD MANUAL

U.S. Department of the Interior
Bureau of Reclamation

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

The information contained in this report regarding commercial products or firms may not be used for advertising or promotional purposes and is not to be construed as an endorsement of any product or firm by the Bureau of Reclamation.

The information contained in this report was developed for the Bureau of Reclamation; no warranty as to the accuracy, usefulness, or completeness is expressed or implied.

Acknowledgments

The preparation of this manual has involved nearly every engineering geologist and geophysicists within Reclamation. Many geotechnical engineers offered comments that have been incorporated into the manual. Their input is greatly appreciated.

Special recognition is given to Mr. Jerry S. Dodd, Chief, Division of Geology (Retired) who initiated the manual; to N. Ben Bennett, II, Jerry's Successor who kept the manual moving. To Richard H. Throner, who probably wrote more paragraphs, served on more committees and has more contact with authors and consultants than any other Reclamation geologist and to Sam R. Bartlett who compiled and printed the early version of the manual we extend our thanks and appreciation.

Also, to the Regional Geologists and their staffs we extend our thanks and appreciation for their work into the manual. The manual would not be complete without the drawings and figures; to the engineering and physical scientists technicians we extend our gratitude and thanks.

FOREWORD

This version of the Engineering Geology Field Manual presents the requirements and procedures for the collection of geologic data obtained by the Bureau of Reclamation. The intent is to establish common guidelines, procedures, and concepts for the collection, evaluation, and presentation of geologic information. The analysis of geologic conditions, the preparation of designs and specifications and effective construction monitoring require consistent, comprehensive, and timely geologic information. The use of these guidelines by all Reclamation engineering geologists collecting, documenting, evaluating and presenting geologic information will promote consistency, help to assure that the required evaluations and data are complete, and promote integration and coordination of geologic and engineering activities.

It is hoped that this Engineering Geology Field Manual, in conjunction with the Engineering Geology Office Manual, will form the basis of the exchange of ideas which will be mutually beneficial to all Reclamation geologists.

Experienced geologists will find useful reminders about new procedures and special techniques, while the newer employees can look upon the guide as an opportunity to expand their familiarity with geology as practices in the Bureau of Reclamation.

Review and comments on the manual are encouraged, and if you have comments or suggested addition, please forward them to either individual manual committee members or directly to the Denver Office, Attention: Chief, Geology Branch, D-3610.

Steve D. Markwell
Chief, Geotechnical Engineering and Geology Division

CONTENTS

Acknowledgments

Foreword

PART I

Page

Chapter 1 Introduction 1

Chapter 2 Geologic Terminology and Classifications for Geologic Materials 3

Established references for geologic terminology ... 3
Geologic classification of materials 4
Engineering classification of geologic materials..... 5
Application and use of standard indexes, terminology, and descriptors 8
Units of measurements for geologic logs of exploration, drawings, and reports 11
Bibliography 12

Chapter 3 Classification and Description of Soil and Surficial Deposits 15

General 15
Classifications of soils 18
Description of the physical properties of soil 33
Narrative descriptions and examples 39
Use of soil classifications as secondary identification methods for materials other than natural soils 42
Bibliography 47

Chapter 4 Classification of Rocks and the Description of Physical Properties of Rock 49

Introduction 49
Rock classification 49
Description of rock 51
Example descriptions 72
Bibliography 75

Page

Chapter 5 Terminology and Descriptions for Discontinuities 77

General.. 77
Discontinuity terminology 77
Indexes for describing fracturing.......................... 81
Description of fractures.. 84
Descriptions of shears and shear zones 98
Bibliography.. 109

Chapter 6 Geologic Mapping and Documentation for Design and Construction........... 111

Responsibilities of the engineering geologist......... 111
Development of a study plan................................ 112
Surface geologic mapping 119
Feasibility preconstruction geologic mapping........ 120
Construction geologic mapping........................... 131
Large excavation mapping 132
Steep slope mapping... 133
Canal and pipeline mapping.................................. 134
Underground geologic mapping 134
Photogeologic mapping.. 138
Analysis of aerial photographs 140
Availability of imagery 142
References.. 144
Bibliography.. 145

Chapter 7 Discontinuities Surveys 147

General.. 147
Areal mapping.. 147
Detailed line mapping 149
Bibliography... 155

Chapter 8 Considerations for the Development of an Effective and Efficient Exploration Drilling Program 157

Introduction 157
Preplanning the exploration drilling program 157
Preparation of drilling specifications and format .. 162

CONTENTS

Page

Chapter 9 Ground-Water Data Acquisition Methods 165

Introduction 165
Background data—review of theories and terminology 165
Design and installation of monitoring wells or piezometers 167
Design and installation techniques of a ground-water monitoring well 169
Methods used to monitor surface and subsurface waters 172
Methods and techniques used to estimate flows from seeps, springs, and other small surface drainages 177
Computer-based monitoring systems 178
Special applications 180
Data-base management and data presentation 180
Definitions 181
References 183
Bibliography 183

Chapter 10 Guidelines for Core Logging 185

General 185
Format and required data for the final geologic log 188
Method of reporting orientation of planar discontinuities and structural features 220
Core recovery and core losses 220
Samples 222
Core photography 222
Equipment necessary for preparing the field log 225
Instruction to drillers, daily drill reports, and general drilling procedures 227

Chapter 11 Instructions for Logging Soils and Surficial Deposits 239

General 239
Format of word descriptions for test pits and auger hole logs 251
Format of word descriptions for drill hole logs 258
Equipment necessary for preparing the field log 270

Page

Example descriptions and format 271
Laboratory classifications in addition to visual classifications 271
Word descriptions for various soil classifications 272
Reporting laboratory data 284
Special cases for USCS classification 285
Reporting in-place unit weight tests 286
Bibliography 288

PART II

Chapter 12 Introduction to Part II 289

Chapter 13 Geophysical Investigations, Services, and Equipment Capabilities 291

Surface geophysical techniques 295
Project planning checklist 318
Geophysical services and geophysical equipment capabilities 319
Glossary 326
Bibliography 341

Chapter 14 Borehole Geophysical and Wireline Surveys 349

Introduction 349
Electrical logging techniques 349
Nuclear radiation logging techniques 361
Acoustic/seismic logging techniques 369
Borehole optical systems 379
Other wireline systems 386
Application and data acquisition 392
Bibliography 395

Chapter 15 Standards for Care, Retention, and Disposal of Drill Core and Subsurface Soil and Rock Samples 397

General 397
Location of storage facilities 398
Conditions of storage 400
Length of storage 401
Disposal of core and samples 404

Page

Retention of rock core and samples 405
Boxing and labeling drill core for storage 405

Chapter 16 Remote Sensing Techniques 407

Introduction 407
Imaging systems 407
Resolution 408
Photography 408
Thermal infrared imagery 409
MSS (Multi spectral scanner) imagery 409
Airborne MSS imagery 410
Satellite MSS imagery 410
Radar imagery 411
Applications to engineering geology 411
Availability of imagery 411
Mission planning 412
Time and cost estimating 412
Technical assistance 412
Bibliography 413

Chapter 17 Construction Dewatering 415

Scope 417
Responsibility and role of the engineering geologist 417
Recognition of problem areas 419
Exploration program input 420
Design data requirements, responsibilities, and methods of collection and presentation 421
The role of the geologist during construction dewatering 425
Monitoring 426
Performance evaluation during construction 435
Final reporting 435
Construction dewatering bibliography 435

Chapter 18 Geologic Aspects of Blast Design 437

Introduction 437
Properties and geology of the rock mass 438
Surface blasting 444
Underground blasting 465
Controlled blasting techniques 475
Riprap blasting techniques 482

Page
Bibliography 483
Glossary of terms used in explosives and blasting 484

Chapter 19 Waste in Riprap Production 513

Introduction 513
Contributors to waste in riprap production 513
Gradation requirements 514
Production methods 515
Collected data presentation 515

Chapter 20 Data Collection for Grouting 529

Introduction 529
Site geology 529
Literature search 530
Geologic structure 530
Geohydrology 531
Investigation methods 534
Water testing 535
Test grouting 540
Summary 542
Bibliography 542

Appendix A Abbreviations Commonly Used in Bureau of Reclamation Engineering Geology 547

Appendix B Techniques for Plotting Geologic Structures 559

Appendix C Petrographic, Soil, and Rock Mechanics Tests and Services Available at the Denver Office 569

Appendix D Miscellaneous Emperical Data 585

Appendix E Guidelines for Geologists Involved in Instrumentation Installations .. 595

TABLES

Table Page
2-1 Ground behavior for earth tunneling with steel supports 9
2-2 Useful conversion factors 12

CONTENTS

Table Page

3-1 Basic group names, primary groups 23
3-2 Basic group names, 5 to 12 percent fines laboratory criteria 23
3-3 Criteria for describing dry strength 27
3-4 Criteria for describing dilatancy 27
3-5 Criteria for describing toughness........................ 28
3-6 Criteria for describing plasticity 29
3-7 Identification of inorganic fine-grained soils from manual tests 31
3-8 Criteria for describing angularity of coarse-grained particles.. 34
3-9 Criteria for describing particle shape 34
3-10 Criteria for describing moisture condition 35
3-11 Criteria for describing reaction with HCl......... 36
3-12 Criteria for describing consistency in fine-grained soils 36
3-13 Criteria for describing cementation.................. 37
3-14 Particle sizes 38
3-15 Checklist for the description of soil classification and identification...................... 40
3-16 Sample of test results summary 44
3-17 Soils classification chart 46

4-1 Igneous and metamorphic rock grain size descriptors.. 59
4-2 Sedimentary and pyroclastic rock particle—size descriptors.. 60
4-3 Bedding, foliation, or flow texture descriptors.. 62
4-4 Weathering descriptors....................................... 65
4-5 Durability index descriptors 67
4-6 Rock hardness/strength descriptors 71

5-1 Fracture density descriptors 82
5-2 Fracture spacing descriptors............................... 87
5-3 Fracture continuity descriptors........................... 88
5-4 Descriptors for recording fracture ends in joint surveys 88
5-5 Fracture openness descriptors 89
5-6 Fracture filling thickness descriptors 90
5-7 Fracture healing descriptors............................... 92
5-8 Fracture roughness descriptors.......................... 93
5-9 Fracture moisture condition descriptors........... 95

Table Page

11-1 Checklist for the description of soils in test pit and auger hole logs 252

13-1 The determination of moduli and ratios for typical velocities of earth materials from refraction surveys 301
13-2 Representative values of resistivity 306

18-1 Typical rocks, densities, and unit weights 439
18-2 Approximate burden/charge diameter ratios for bench blasting 452
18-3 Typical powder factors for surface blasting 462
18-4 Parameters for presplitting 478
18-5 Parameters for smooth blasting 480
18-6 Parameters for cushion blasting 482

19-1 Rock types vs. usable quantity of riprap 514
19-2 Data on metamorphic rock and riprap quarries 517
19-3 Data on igneous rock and riprap quarries 519
19-4 Data on sedimentary rock and riprap quarries 523

C-1 Denver Office petrographic laboratory analyses 570
C-2 Denver Office rock mechanics tests 576
C-3 Denver Office rock mechanics field tests/services 580
C-4 Denver Office soil laboratory tests 582

FIGURES

Figure Page
3-1 Modifiers to basic soil group names (for visual classification) 19
3-2 Flow chart for inorganic fine-grained soils, visual method 20
3-3 Flow chart for organic soils, visual method 21
3-4 Flow chart for coarse-grained soils, visual method 22
3-5 Plasticity chart 30

4-1 Field classification of igneous rocks 52
4-2 Field classification of sedimentary rocks 53
4-3 Field classification of metamorphic rocks 54

CONTENTS

Figure Page

4-4 Field classification of pyroclastic rocks 55
4-5 Charts for estimating percentage of composition of rocks and sediments............. 56
4-6 Permeability conversion chart 73

5-1 Rock quality designation (RQD) computation .. 79
5-2 Comparison of true and apparent spacing........ 86
5-3 Examples of roughness and waviness of fracture surfaces, typical roughness profiles, and terminology 94
5-4 Uniform shear zone... 99
5-5 Layered shear zone (2 zones or layers)............. 99
5-6 Layered shear zone (3 layers) 100
5-7 Uniform shear zone with veinlets..................... 100
5-8 Uniform shear zone (composite)....................... 101
5-9 Standard descriptors and descriptive criteria for discontinuities.. 103

6-1 Process of engineering geology mapping.......... 113
6-2 Sample trench log.. 125
6-3 Sample of completed trench log....................... 130
6-4 Springline projection of tunnel geology 135
6-5 Map layout of tunnel for geologic mapping 136
6-6 Graphic method for plotting tunnel geology.... 137
6-7 Graphic method for plotting tunnel geology—springline projection 138
6-8 Graphic method for plotting tunnel geology (sheet 2) 139

7-1 Equatorial equal area net (Schmidt Net) 148
7-2 Polar equal-area net... 149
7-3 Influence of number of fractures on confidence of joint sets 150
7-4 Form used for detail line mapping 152
7-5 Data record for detail line mapping 153
7-6 Data record for detail line map........................ 154

10-1 Drill hole log, DH-123....................................... 189
10-2 Drill hole log, B-102, for standard Penetration Test.. 191
10-3 Drill hole log, DH-SP-2 195
10-4 Drill hole log, DH-400 197
10-5 Geologic log of drill hole, SPT-107-2............... 204
10-6 Drill hole log, DH-DN/P-60-1 207
10-7 Daily drill report 226

Figure Page

10-8 Water testing record 232
10-9 Use of a cardboard PVC half-round and plastic wrap to prevent disturbance and drying out of shear zone, special samples, or fracture zones 234
10-10 N-size core box 235

11-1 Log of test pit or auger hole 240
11-2 Clean coarse-grained soils 241
11-3 Fine-grained soils 242
11-4 Soil classifications based on laboratory test data 243
11-5 Auger hole with samples taken 244
11-6 Reporting laboratory classification in addition to visual classification 245
11-7 Undisturbed soils 246
11-8 Coarse-grained soils with fines 247
11-9 Coarse-grained soils with dual symbols 248
11-10 Reporting in-place unit weight tests and percent compaction 249
11-11 Soil with measured percentages of cobbles and boulders 250
11-12 Soil with more than 50 percent cobbles and boulders 257
11-13 Borderline soils 259
11-14 Test pit with samples taken 260
11-15 Disturbed samples 261
11-16 Two descriptions from the same horizon 262
11-17 Drill hole advanced with tri-cone roller rock ... 264
11-18 Log showing poor recovery 265
11-19 Log of landslide material (a) 267
11-20 Log of landslide material (b) 268
11-21 Log of bedrock 269
11-22 Geologic interpretation in test pit (sheet 1) 273
11-23 Geologic interpretation in test pit (sheet 2) 274
11-24 Geologic interpretation in test pit (geologic profile) 275
11-25 Geologic interpretation in test pit (sheet 3) 276
11-26 Geologic interpretation in test pit (sheet 4) 277
11-27 Geologic interpretation in test pit (geologic profile 2) 278
11-28 Geologic interpretation in test pit (sheet 5) 279
11-29 Geologic interpretation in test pit (sheet 6) 280
11-30 Geologic interpretation in test pit (sheet 7) 281

Figure Page

11-31 Geologic interpretation in test pit (sheet 8)...... 282
11-32 Geologic interpretation in test pit (geologic profile 3) 283

13-1 Relative importance of geophysical methods in civil engineering. 293
13-2 Simplified diagram of seismic refraction test.... 297
13-3 Shear wave seismogram 300
13-4 Types of surface waves 304
13-5 Dipole resistivity array 309
13-6 Ground penetrating radar schematic 313

14-1 Spontaneous potential survey elements............ 352
14-2 Electric log showing responses of SP and resistivity devices in different strata............ 353
14-3 Single-point resistivity array............................ 355
14-4 Multiple-electrode resistivity arrays 357
14-5 Focused current, or guard, resistivity array...... 358
14-6 Microlog resistivity logging device................... 360
14-7 Elements of the natural gamma (gamma ray) logging system.. 364
14-8 Gamma-gamma and neutron logging systems... 366
14-9 Typical curve response for nuclear radiation logs.. 368
14-10 Elements of a simple wireline acoustic velocity device 371
14-11 The acoustic velocity logging displays 373
14-12 Part of an actual record of intensity—modulated acoustic logging device............... 374
14-13 Elements of an acoustic borehole imaging system... 375
14-14 Traces of planar discontinuities 377
14-15 Essential elements of crosshole seismic test....... 378
14-16 Elements of a borehole television logging system... 381
14-17 Schematic drawing of NX borehole film camera in borehole 383
14-18 Projection of borehole wall image into the film plane 385
14-19 Log of a six-arm mechanical caliper 388
14-20 Elements of borehole gravity logging 390
14-21 Example for Geophysical Exploration Matrix—Phase I 393

17-1 Aquifer test, plan, and sections 427

Figure Page

17-2 Aquifer test data 429

18-1 Effect of jointing on the stability of an excavation 442
18-2 Tight and open corners caused by jointing 442
18-3 Stemming through weak material and open beds 443
18-4 Two methods of breaking a hard collar zone 444
18-5 The effect of large and small blastholes on unit costs 446
18-6 The effects of jointing on selection of blasthole size 448
18-7 Three basic types of drill patterns 449
18-8 Corner cut staggered pattern with simultaneous initiation within rows 449
18-9 V-Echelon blast round 450
18-10 Isometric view of a bench blast 451
18-11 Comparison of a 12-1/4 inch (305 mm) diameter blasthole (stiff burden) with a 6-inch (152 mm) diameter blasthole (flexible burden) in a 40-foot (12.2 m) bench 453
18-12 Effects of insufficient and excessive spacing 456
18-13 Staggered blast pattern with alternate delays 458
18-14 Staggered blast pattern with progressive delays 458
18-15 The effect of inadequate delays between rows 460
18-16 Types of opening cuts 463
18-17 Six designs for parallel hole cuts 467
18-18 Blast round for soft rock using sawed kerf 469
18-19 Nomenclature for blasthole in a heading round 470
18-20 Angled cut blast rounds 471
18-21 Parallel hole cut blast rounds 471
18-22 Fragmentation and shape of muckpile as a function of type of cut 472
18-23 Fragmentation and shape of muckpile as a function of delay 473
18-24 Typical burn cut blast round delay pattern 473
18-25 Typical V-cut blast round delay pattern 474
18-26 Shape of muckpile as a function of firing order 475
18-27 Typical presplit blasthole loading 477
18-28 Typical smooth blasting pattern 479

CONTENTS

Figure Page

18-29 Cushion blasting techniques.............................. 481

B-1 Projecting a fault between dozer trenches........ 559
B-2 Slope angles, dips, and percent grades for slope design.. 561
B-3 Apparent dip computer 563
B-4 Projecting surface geology to cross sections 565
B-5 Drill hole plan and profile 567

D-1 General rock bolt chart 587
D-2 Comparison of transmissivity, specific capacity, and well potential.. 589
D-3 Comparison of permeability and representative acquifer materials................. 590
D-4 Presumptive bearing capacity values, granular soils 591
D-5 Presumptive bearing capacity values, clay and mixed soils 592
D-6 Dip projection chart 593

Chapter 1

INTRODUCTION

The purpose of this manual is to provide the necessary "how to" suggestions for undertaking most field oriented geologic investigations performed by Bureau of Reclamation geologists. This volume provides reference and terminology material used for classification and descriptions of soil, surficial deposits, rock units and rock discontinuities. In addition, guidelines are presented for geologic mapping, discontinuity surveys, sampling, testing, and instructions for core logging. Brief coverage of ground-water data acquisition and analysis as well as ground behavior measurement is also included.

As stated, the intent of this manual is to provide "how to" guidelines for field work leading to the development of geologic concepts and reports. However, complex sites and conditions may require modification or expansion of the criteria and indices presented in these guidelines. This approach is acceptable and encouraged in isolated cases. Whenever the guidelines are deviated from, the modifications and expansions to the guidelines must be documented in the technical reports and on the accompanying drawings for each feature.

Many of the chapters in this manual are preliminary. Some chapters are considered complete and have been accepted by Reclamation geologists. Critical comments including suggestions for improvement are being solicited from all geology users in the Bureau of Reclamation. The ultimate goal for this manual is Reclamation-wide acceptance and use of the guidelines.

Chapter 2

GEOLOGIC TERMINOLOGY AND CLASSIFICATIONS FOR GEOLOGIC MATERIALS

Established References for Geological Terminology

Adaptations or refinements of the Reclamation standards presented in this and subsequent chapters, if required for a more precise definition, may be established to meet specific design requirements or site-specific geologic complexity when justified. If terminology or standard descriptions are modified, they must be substantiated and redefined by the applicable geologic reports and geologic notes on drawings.

The *Glossary of Geology,* Third Edition [1]*, published by the AGI (American Geological Institute), 1980, is accepted by the Bureau of Reclamation as the standard for definitions of geologic words and terms except for the nomenclature, definitions or usage established in this chapter and Chapters 3, 4, and 5.

The NASC (North American Stratigraphic Code) [2] is the accepted system for classifying and naming stratigraphic units. However, Reclamation's engineering geology programs are interested primarily in the engineering properties of geologic units, not in the details of formal stratigraphic classification. Stratigraphic names are not always consistent in the literature, often change from one locality to another, and do not necessarily convey engineering properties or rock types. Use of stratigraphic names in Reclamation documents normally will be informal (lower case) (see NASC for discussion of formal vs. informal usage). Reclamation geologists should be careful not to use names previously used formally in the area in an informal sense. Exceptions to informal usage are for names previously used formally in the area in discussions of geologic setting or regional geology. Normally, the first use of formal names in a report should include a reference to a geologic map or publication in which the term is defined to indicate how Reclamation is using the term.

***Brackets refer to bibliography entries at end of chapter.**

Geologic Classification of Materials

The following definitions of geologic materials more fully satisfy general Reclamation usage and supersede those in the *Glossary of Geology.* These definitions are for geologic classification of materials. They should not be confused with engineering classifications of materials such as rock and soil, or rock and common excavation.

- Bedrock.—A general term that includes any of the generally indurated or crystalline materials that make up the Earth's crust. Individual stratigraphic units or units significant to engineering geology within bedrock may include poorly or nonindurated materials such as beds, lenses, or intercalations. These may be weak rock units or interbeds consisting of clay, silt, and sand (such as the generally soft and friable St. Peter Sandstone), or clay beds and bentonite partings in siliceous shales of the Morrison formation.

- Surficial deposits.—The relatively younger materials occurring at or near the Earth's surface overlying bedrock. They occur as two major classes: (1) transported deposits generally derived from bedrock materials by water, wind, ice, gravity, and man's intervention, and (2) residual deposits formed in situ as a result of weathering processes or by the accumulation of organic matter. They may be stratified or unstratified such as soil profiles, basin fill, alluvial or fluvial deposits, landslides, or talus. They may be partially indurated or cemented by silicates, oxides, carbonates, or other chemicals (caliche or hardpan). This term is often used interchangeably with "overburden". The use of "overburden" is discouraged in the Bureau of Reclamation.

In some localities, where the distinction between bedrock and surficial deposits is not clear, even if assigned a stratigraphic name, a uniform practice should be established and documented and that definition followed for the site or study.

Guidelines for the collection of data pertaining to bedrock and surficial deposits are presented in Chapter 6.

Engineering Classification of Geologic Materials

General

Geologic classification of materials into surficial deposits and bedrock is insufficient for engineering purposes. Usually, surficial deposits are described as soil for engineering purposes, and most bedrock is described as rock; however, there are exceptions. Structure excavations often are classified as to their ease of excavation in contract documents. Also, classification systems for tunneling in geologic materials have been established for contract documents. The use of these classifications systems is provided in the following subsections.

Classification as Soil or Rock

In engineering applications, ***soil*** may be defined as generally nonindurated accumulations of solid particles produced by the physical and/or chemical disintegration of bedrock and which may or may not contain organic matter. Surficial deposits such as colluvium, alluvium, or residual soil, normally are described using USBR (Bureau of Reclamation) 5000, Determining Unified Soil Classification (Visual Method) [3]. American Society for Testing and Materials (ASTM) Standards D2487-85, Standard Test Method for Classification of Soils for Engineering Purposes or D2488-84, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure), which are based on USBR 5000 and 5005 [4] also may be used. Instructions for the description and classification of soils are provided in Chapter 3. Chapter 11 provides instructions for the logging of soils in geologic explorations. In some cases, partially indurated soils may have rock-like characteristics and may be described as rock.

The USDA (United States Department of Agriculture) Agricultural Soils Classification System is used for drainage and land classification and some detailed Quaternary geology studies, such as for seismotectonic investigations.

Rock as an engineering material is defined as lithified or indurated crystalline or noncrystalline materials. Rock is encountered in masses and as large fragments which have consequences to design and construction differing from those of soil. Field classification of igneous, metamorphic, sedimentary, and pyroclastic rocks are provided in Chapter 4. Chapter 4 also presents a suggested description format, standard descriptors, and descriptive criteria for the lithologic and engineering physical properties of rock. Nonindurated materials within bedrock should be described using the USBR soil classification standards and soil descriptors presented in Chapter 3. Engineering and geological classification and description of discontinuities which may be present in either soil or rock are provided in Chapter 5.

Classification of Excavations

The engineering classification of excavation as either rock excavation or common excavation, or the definition of rock in specifications must be evaluated and determined for each contract document and will be based on the physical properties of the materials (induration and other characteristics), quantity and method of excavation, and equipment constraints and size.

Classification of Materials for Tunneling

The classification terminology usually used for describing geologic materials for Reclamation tunnels is based on Terzaghi[1] [5]. These classification systems are used by Reclamation geologists for data reports, specifications, and construction monitoring for tunnel designs and construction. When appropriate for design, other load prediction and classification systems may be used such as the Q system developed by the Norwegian Geotechnical Institute (NGI), Rock Mass Rating System Geomechanics Classification (RMR), and Rock Structure Rating (RSR).

The following terms for the classification of rock for tunneling are abstracted from *Representative Ground Parameters for Structural Analysis of Tunnels [6].*

---

[1] For Terzaghi's rock loading classification, see "Rock Tunneling with Steel Supports," R.V. Proctor and T.L. White, 1977, pg. 3. For Terzaghi's Soil Classification for Tunneling, see "Representative Ground Parameters for Structural Analysis of Tunnel "in Report No. FNNA/RD-80 1012, Volume 1, Federal Highway Administration, Washington, D.C. [6]."

- Intact rock contains neither joints nor hairline cracks. Hence, if it breaks, it breaks across sound rock. On account of the injury to the rock due to blasting, spalls may drop off the roof several hours or days after blasting. This is known as spalling condition. Hard, intact rock may also be encountered in the popping condition (rock burst) involving the spontaneous and violent detachment of rock slabs from sides or roof.

- Stratified rock consists of individual strata with little or no resistance against separation along the boundaries between strata. The strata may or may not be weakened by transverse joints. In such rock, the spalling condition is quite common.

- Moderately jointed rock contains joints and hairline cracks but the blocks between joints are locally grown together or so intimately interlocked that vertical walls do not require lateral support. In rocks of this type, both the spalling and the popping condition may be encountered.

- Blocky and seamy rock consists of chemically intact or almost intact rock fragments which are entirely separated from each other and imperfectly interlocked. In such rock, vertical walls may require support.

- Crushed but chemically intact rock has the character of a crusher run. If most or all of the fragments are as small as fine sand and no recementation has taken place, crushed rock below the water table exhibits the properties of a water-bearing sand.

- Squeezing rock slowly advances into the tunnel without perceptible volume increase. Prerequisite for squeeze is a high percentage of microscopic and submicroscopic particles of micaceous minerals or of clay minerals with a low swelling capacity.

- Swelling rock advances into the tunnel chiefly on account of expansion. The capacity to swell seems to be limited to those rocks which contain smectite, a montmorillonite group of clay minerals, with a high swelling capacity.

Although the terms are defined, no distinct boundaries exist between rock categories. Wide variations in the physical properties of rocks classified by these terms and rock loading are often the case.

Designers and contract documents often use Terzaghi's rock loading classifications for support design. These are given in *Rock Tunneling with Steel Supports* [5].

Table 2-1, Soil classification for tunneling, is from *Representative Ground Parameters for Structural Analysis of Tunnels* [6].

Application and Use of Standard Indexes, Terminology, and Descriptors

This section and subsequent Chapters 3, 4, and 5 provide definitions and standard descriptors for physical properties of geologic materials which are of engineering significance. The ability of a foundation to support loads imposed by various structures depends primarily on the deformability and stability of the foundation materials and the groundwater conditions. Description of geologic and some manmade materials (embankments) is one of the geologist's direct contributions to the design process. Judgment and intuition alone are not adequate for the safe and economical design of large complex engineering projects. Preparation of geologic logs, maps and sections, and detailed descriptions of observed material is the least expensive aspect and most continuous record of a subsurface exploration program. It is imperative to develop design data properly because recent advances in soil and rock mechanics have enabled engineers and geologists to analyze more conditions than previously possible. These analyses rely on physical models that are developed through geologic observation and which must be described without ambiguity.

The need for standard geologic terminology, indexes, and descriptors has long been recognized because it is important that design engineers and contractors, as well as geologists, be able to have all the facts and qualitative information as a common basis to arrive at conclusions from any log of exploration, report, or drawing, regardless of who prepared it. Therefore, geologic terminology, standard descriptors, and descriptive criteria for physical properties have been

Table 2-1. – Ground Behavior for Earth Tunneling with Steel Supports (after Terzaghi, 1950) [7].

Ground classification	Reaction of Ground to Tunneling Operation
HARD	Tunnel heading may be advanced without roof support.
FIRM	Ground in which a roof section of a tunnel can be left unsupported for several days without inducing a perceptible movement of the ground.
RAVELING	Chunks or flakes of soil begin to drop out of roof at some point during the ground-movement period.
SLOW RAVELING	The time required to excavate 5 feet of tunnel and install a rib set and lagging in a small tunnel is about 6 hours. Therefore, if the stand-up time of a raveling ground is more than 6 hours, by using ribs and lagging the steel rib sets may be spaced on 5-foot centers. Such a soil would be classed as slow-raveling.
FAST RAVELING	If the stand-up time is less than 6 hours, set spacing must be reduced to 4 feet, 3 feet, or even 2 feet. If the stand-up time is too short for these smaller spacings, liner plates should be used, either with or without rib sets, depending on the tunnel size.
SQUEEZING	Ground slowly advances into tunnel wihtout any signs of fracturing. Yet the loss of ground caused by squeeze and the resulting settlement of the ground surface can be substantial.
SWELLING	Ground slowly advances into the tunnel partly or chiefly because of an increase in the volume of the ground. The volume increase is in response to an increase of water content. In every other respect, swelling ground in a tunnel behaves like a stiff non-squeezing, or slowly squeezing, non-swelling clay.
RUNNING	The removal of lateral support on any surface rising at an angle of more than 34° (to the horizontal) is immediately followed by a running movement of the soil particles. This movement does not stop until the slope of the moving soil becomes roughly equal to 34°. If running ground has a trace of cohesion, then the run is preceded by a brief period of progressive raveling.
VERY SOFT SQUEEZING	Ground advances rapidly into tunnel in a plastic flow.
FLOWING	Ground supporting a tunnel cannot be classified as flowing ground unless water flows or seeps through it toward the tunnel. For this reason, a flowing condition is encountered only in free air tunnels below the water table or under compressed air when the pressure is not high enough in the tunnel to dry the bottom. A second prerequisite for flowing is low cohesion of soil. Therefore, conditions for flowing ground occur only in inorganic silt, fine silty sand, clean sand or gravel or sand- and -gravel with some clay binder. Organic silt may behave either as a flowing or as a very soft, squeezing ground.

established so that geologic data are recorded uniformly, objectively, consistently, and accurately. The application of these indexes, terminology, descriptors, and various manual and visual tests must be applied consistently by all geologists for each particular project. The need to calibrate themselves with others performing similar tests and descriptions is imperative to ensure that data are recorded and interpreted uniformly. The use of these standard descriptors and terminology is not intended to replace the geologist's or engineer's individual judgment. The established standard qualitative and quantitative descriptors will assist newly employed geologists and engineers in adapting to Reclamation terminology and procedures, permit better analysis of data, and permit better understanding by other geologists and engineers, and by contractors. Most of the physical dimensions established for the descriptive criteria pertaining to rock and discontinuity characteristics have been established using a 1-3-10-30-100 progression for consistency, ease of memory, conversion from English to SI metric (30 mm = 0.1 ft) units, and to conform to many established standards used throughout the world. If adhered to, their use will help to improve analysis, design and construction considerations, and specifications preparation. Contractor claims also should be reduced due to consistent and well defined terminology and descriptors.

Alphanumeric values for many physical properties have been established to enable the geotechnical engineer and engineering geologist to analyze the geologic data readily. These alphanumeric descriptors also will assist in compilation of data bases and computer searches when using computer generated logs. For consistency, the lower the alphanumeric value, the more favorable the condition being described. However, alphanumeric codes do not replace a complete description of what is observed. A complete description provides physical dimensions including a range and/or average in size, width, length or other physical property, and/or descriptive information.

It is important to start physical testing of the geologic materials as early as possible in an exploration program; descriptors alone are not sufficient. As data are interpreted, index properties tests can be performed in the field to obtain preliminary strength estimates for representative materials or materials requiring special consideration. The scope of such a program must be tailored to each future. Tests which are to be considered include point load, Schmidt hammer, sliding tilt, and pocket Torvane or penetrometer tests. These tests are described briefly in Chapters 4 and 5. Indexes to be considered include rock hardness, durability (slaking), and RQD (Rock Quality Designation). The type of detailed laboratory studies can be formulated better and the amount of sampling and testing may be reduced if results from field tests are available.

Units of Measurements for Geologic Logs of Exploration, Drawings, and Reports

Metric Units

For metric specifications and studies, (including most seismotectonic evaluations), SI metric (International System of Units) presented in Reclamation's *Metric Manual* [8] shall be used. Logs of exploration providing depth measurements are to be given to tenths or hundredths of meters. All linear measurements such as particle or crystal sizes, ranges or averages in thickness, openness, and spacing, provided in descriptor definitions in Chapters 3, 4, and 5 should be expressed in millimeters or meters as appropriate. Pressures should be given in pascals (Pa). Permeability (hydraulic conductivity) should be in centimeters per second (cm/s).

English Units (U.S. Customary)

For specifications and studies using U.S. customary or English units (inch-pound), depth measurements should be given in feet and tenths of feet. Ranges in thickness, openness, and spacing, are preferred in tenths or hundredths of a foot, or feet as shown in the descriptor definitions in Chapters 4 and 5. Pressure should be in pound-force per square inch (lbf/in^2). Permeability should be in feet per year (ft/yr). The exceptions to the use of English units (inch-pound) are for describing particle and grain sizes and age dating. Particle sizes for soils classified using ASTM/USCS should be in metric units on all logs of exploration. For description of bedrock, particle and grain sizes are to be in millimeters.

Age Dates

If age dates are abbreviated, the NASC recommends SI units (for example, *ka* for thousand years and *Ma* for million years), but *my* or *m.y.* (million years) for time intervals (for example, ". . . during a period of 40 my . . .").

Conversion of Metric and English (U.S. Customary) Units

Table 2-2 provides many of the most frequently used SI metric and English (U.S. Customary) units for geotechnical work. Additional conversions are available in the *Metric Manual* and the *Earth Manual* [9].

Table 2-2. – Useful conversion factors—metric and English Units (inch-pound).

To reduce units in column 1 to units in column 4, multiply column 1 by the factor in column 2.

To reduce units in column 4 to units in column 1, multiply column 4 by the factor in column 3.

Column 1	Column 2	Column 3	Column 4
	Length		
inch (in)	2.540×10^{1}	3.937×10^{-2}	millimeter (mm)
hundredths of feet	3.048×10^{2}	3.281×10^{-3}	millimeter (mm)
foot (ft)	3.048×10^{-1}	3.281	meter (m)
mile (m)	1.6093	6.2137×10^{-1}	kilometer (km)
	Area		
square inch (in^2)	6.4516×10^{-4}	1.550×10^{-3}	square meter (m^2)
square foot (ft^2)	9.2903×10^{-2}	1.0764×10^{1}	square meter (m^2)
acre	4.0469×10^{-1}	2.4711	hectare
square mile (mi^2)	0.386×10^{-2}	259.0	hectares
	Volume		
cubic inch (in^3)	1.6387×10^{-2}	6.102×10^{-2}	cubic centimeter (cm^3)
cubic feet (ft^3)	2.8317×10^{-2}	3.5315×10^{1}	cubic meter (m^3)
cubic yard (yd^3)	7.6455×10^{-1}	1.3079	cubic meter (m^3)
cubic feet (ft^3)	7.4805	1.3368×10^{-1}	gallon (gal)
gallon (gal)	3.7854	2.6417×10^{-1}	liter (L)
acre-feet (acre-ft)	1.2335×10^{3}	8.1071×10^{-4}	cubic meter (m^3)
	Flow		
gallon per minute (gal/min)	6.309×10^{-2}	1.5850×10^{1}	liter per second (L/s)
cubic foot per second (ft^3/s)	4.4883×10^{2}	2.228×10^{-3}	gallons per minute (gal/min)
	1.9835	5.0417×10^{-1}	acre-feet per day (acre-ft/d)
cubic foot per second (ft^3/s)	7.2398×10^{2}	1.3813×10^{-3}	acre-feet per year (acre-ft/yr)
	2.8317×10^{-2}	3.531×10^{1}	cubic meters per second (m^3/s)
	8.93×10^{5}	1.119×10^{-6}	cubic meters per year (m^3/yr)
	Permeability		
k, feet/year	9.651×10^{-7}	1.035×10^{6}	*k*, centimeter per second (cm/sec)
	Density		
pound-mass per cubic foot (lb/ft^3)	1.6018×10^{1}	6.2429×10^{-2}	kilogram per cubic meter (kg/m^3)
	Unit Weight		
pound force per cubic foot (lb/ft^3)	0.157	6.366	kilonewton per cubic meter (kN/m^3)
	Force		
ton	8.89644	1.12405×10^{-1}	kilonewton (kN)
pound-force	4.4482×10^{-3}	224.8096	kilonewton (kN)
	Temperature		
	°C = 5/9 (°F − 32°)	°F = (9/5 °C) + 32°	

BIBLIOGRAPHY

[1] American Geologic Institute (AGI), *The Glossary of Geology,* 3rd edition, Alexandria VA, 1980.

[2] The American Association of Petroleum Geologists Bulletin, v. 67, No. 5, pp. 841-875, May 1983.

[3] Bureau of Reclamation, Geotechnical Branch Training Manual No. 4, Denver CO, 1986.

[4] Bureau of Reclamation, Geotechnical Branch Training Manual No. 5, Denver CO, 1986.

[5] Procter, R.V. and T.L. White, "Rock Tunneling with Steel Supports," p. 3, 1977.

[6] Federal Highway Administration, "Representative Ground Parameters for Structural Analysis of Tunnels", Report No. FHWA/RD-80 1012, v. 1, Washington DC.

[7] Procter, Robert V. and Thomas L. White, "Earth Tunneling with Steel Supports", Commercial Shearing, Inc., 1775 Logan Avenue, Youngstown OH 44501, 1977.

[8] Bureau of Reclamation, *Metric Manual,* Denver CO, 1978.

[9] Bureau of Reclamation, *Earth Manual,* 2nd edition, Denver CO, 1974 (reprinted 1980).

Chapter 3

CLASSIFICATION AND DESCRIPTION OF SOIL AND SURFICIAL DEPOSITS

General

Application

All Reclamation investigations of soils for engineering purposes such as test pits, trenches, auger and drill holes, or other exploratory methods, and surface sampling and mapping, shall be logged and described using USBR standards 5000 [1] and 5005 [2] as modified from the USCS (Unified Soil Classification System). Also, materials in bedrock with the engineering properties of soils are to be described using these standards, Chapter 2. These standards are for a modified USCS consistent with ASTM Designation: D2488. Descriptive criteria and terminology presented are primarily for the visual classification and manual tests. The identification portion of these methods in assigning group symbols is limited to soil particles smaller than 3 inches (75 mm) and to naturally occurring soils. However, this descriptive system may be applied to such materials as shale, shells, and crushed rock, and other classification systems if done according to criteria established in this section. Chapter 11 addresses the logging format and criteria for description of soil in test pit, trench, auger hole, and drill hole logs of exploration.

All investigations associated with land classification for suitability for irrigation, as well as data collection and analyses of soil and substratum materials related to drainage investigations, shall be logged and described using the U.S. Department of Agriculture terminology outlined in appendix I to *Agriculture Handbook No. 436 (Soil Taxonomy)*, dated December 1975 [3].

All soil classifications descriptions for particle sizes are to be in SI (metric) units.

Performing Tests and Obtaining Descriptive Information

The descriptive information required to classify and describe soil materials and presented herein is an aid in the evaluation of significant engineering properties. These guidelines are to be used not only for identification of soils in the field, but also in the office, laboratory, or wherever soil samples are inspected and described.

The descriptive information required for the visual and manual field tests should be used to supplement the classification of a soil as determined by laboratory test [1]. The practice has particular value in identifying and grouping similar soil samples so that only a minimum number of laboratory tests are required for positive soil classification. The ability to identify and describe soils correctly is learned more readily under the guidance of experienced personnel, but it can be acquired systematically by numerically comparing laboratory test results for typical soils of each type with their visual and manual characteristics. When identifying and describing soil samples from a given boring, test pit, group of borings or pits, it is not necessary to follow all of the procedures for every sample. Similar soils may be grouped together; for example, one sample should be identified and described completely, with the others identified as similar based on performing only a few of the identification and descriptive procedures.

The sample used for classification is to be representative of the stratum from which it was obtained by an appropriate accepted or standard procedure and must be identified correctly as to its origin. Remarks as to the origin may take the form of a boring number and depth and/or sample number, a geologic stratum, a pedologic horizon or a location description with respect to a permanent monument, a grid system, or a station number and offset with respect to a stated centerline and a depth or elevation.

Terminology for Soils

Definitions for soil classification and descriptions are in accordance with USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics [4]:

Cobbles and boulders.—For particles retained on a 3-in (75-mm) U.S. Standard sieve, the following terminology shall be used:

- Cobbles—particles of rock that will pass a 12-in (300-mm) square opening and be retained on a 3-in (75-mm) sieve, and

- Boulders—particles of rock that will not pass a 12-in (300-mm) square opening.

Gravel.—Particles of rock that will pass a 3-in (75-mm) sieve and be retained on a No. 4 (4.75-mm) sieve are gravel, and their sizes are further subdivided as follows:

- Coarse gravel—passes 3-in (75-mm) sieve and retained on 3/4-in (19-mm) sieve.

- Fine gravel—passes 3/4-in (19-mm) sieve and retained on No. 4 (4.75-mm) sieve.

Sand.—Particles of rock that will pass a No. 4 (4.75-mm) sieve and be retained on a No. 200 (0.75-µm) sieve are defined as sand, and their sizes are further subdivided as follows:

- Coarse sand—passes No. 4 (4.75-mm) sieve and retained on No. 10 (2.00-mm) sieve.

- Medium sand—passes No. 10 (2.00-mm) sieve and retained on No. 40 (425-µm) sieve.

- Fine sand—passes No. 40 (425-µm) sieve and retained on No. 200 (0.75-µm) sieve.

Clay.—Soil passing a No. 200 (0.75-µm) sieve that can be made to exhibit plasticity within a range of water contents and that exhibits considerable strength when air-dry is a clay. For classification, a clay is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index greater than 4 and the plot of plasticity index versus liquid limit falls on or above the "A"-line.

Silt.—Soil passing a No. 200 (0.75-µm) sieve that is nonplastic or very slightly plastic and that exhibits little or no strength when air-dry is a silt. For classification, a silt is a fine-grained soil, or the fine-grained portion of a soil, with a plasticity index less that 4 or the plot of plasticity index versus liquid limit falls below the "A"-line.

Organic clay.—A clay with sufficient organic content to influence the soil properties is an organic clay. For classification, an organic clay is a soil that would be classified as a clay except that its liquid limit value after ovendrying is less than 75 percent of its liquid limit value before oven drying.

Organic silt.—A silt with sufficient organic content to influence the soil properties is an organic silt. For classification, an organic silt is a soil that would be classified as a silt except that its liquid limit value after oven drying is less than 75 percent of its liquid limit value before oven drying.

Peat.—A soil composed primarily of vegetable tissues in various stages of decomposition, usually with an organic odor, a dark brown to black color, a spongy consistency, and a texture ranging from fibrous to amorphous is a peat.

Classifications of Soils

Group Names and Group Symbols

Soil is given an identification by assigning a group symbol(s) and group name. Important information about the soil is added to the group name by the term "with" when appropriate (fig. 3–1).

Figure 3–2 is a flow chart for assigning typical names and group symbols for inorganic fine-grained soils; figure 3–3 is a flow chart for organic fine-grained soils; and figure 3–4 is a flow chart for coarse-grained soils. These shall be used to assign the appropriate group symbol(s) and name. The identification and naming of a soil based on results of visual and manual tests is presented in a subsequent section. Refer to tables 3–1 and 3–2 for the basic group names. If the soil has properties which do not distinctly place it into a specific group, borderline symbols may be used. A distinction is made between dual symbols and borderline symbols which is discussed in the following paragraphs.

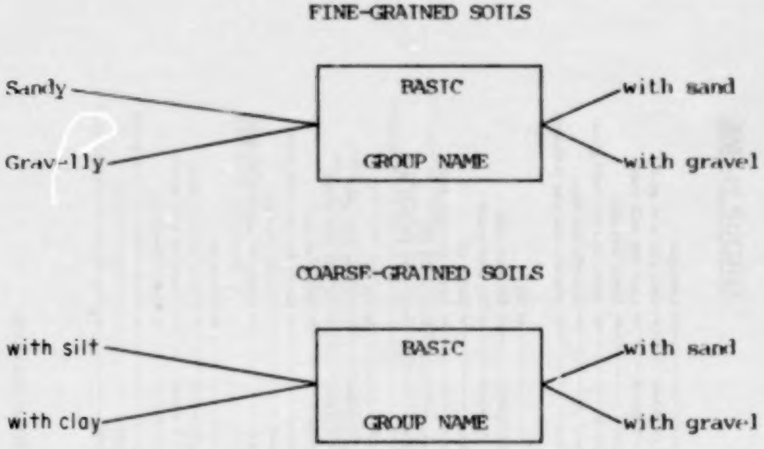


Figure 3-1.—Modifiers to basic soil group names (for visual classification).

Dual Symbols.—A dual symbol (two symbols separated by a hyphen, e.g., GP-GM, SW-SC, CL-ML) should be used to indicate the soil has been identified as having the properties of a classification where two symbols are required. Two symbols are required when the soil has between 5 and 12 percent fines (table 3-2). The laboratory will need the visual classification. A second requirement for dual symbols is when the liquid limit and plasticity index values plot in the CL-ML area of the plasticity chart (table 3-1).

Borderline Symbols.—Two symbols separated by a slash, such as CL/CH, SC/CL, GM/SM, SL/ML, should be used to indicate the soil has been identified as having properties that do not distinctly place the soil into a specific group. Because the classification of soils is based on estimates of particle-size distribution and plasticity characteristics, it may be difficult to clearly identify the soil as belonging to one category. To indicate that the soil may fall into one of two possible basic groups, a borderline symbol may be used with the two symbols separated by a slash. The use of a borderline classification symbol should not be used indiscriminately. Every effort should be made first to place the soil into a single group.

A borderline symbol may be used when the percentage of fines is estimated to be between 45 and 55 percent. One

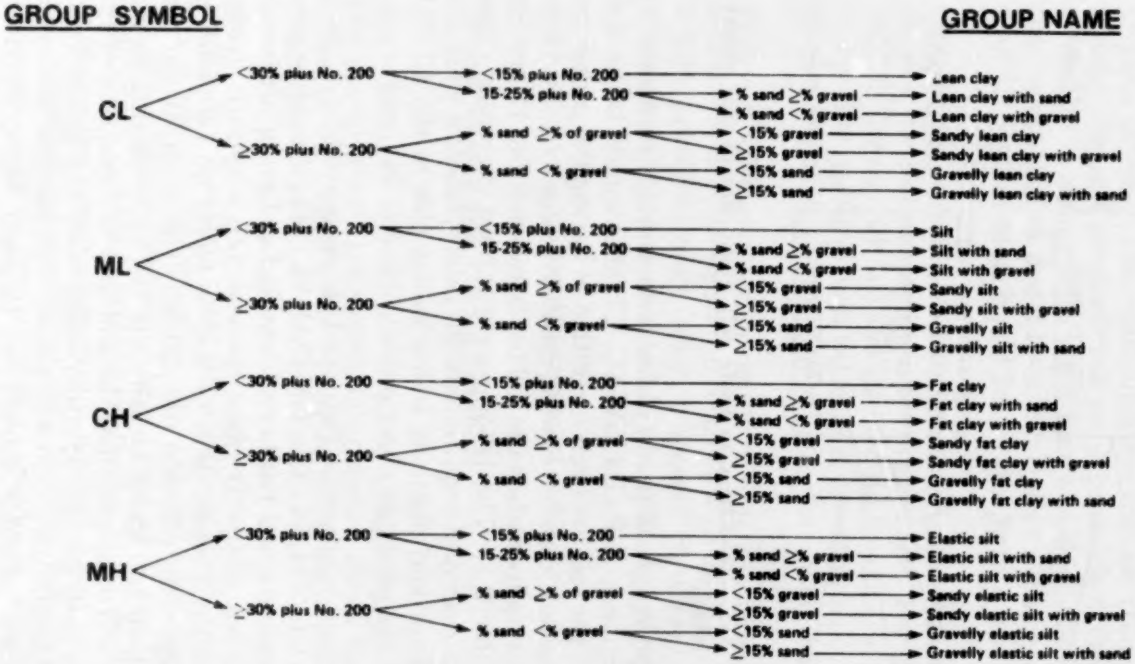


Figure 3-2.—Flow chart for inorganic fine-grained soils, visual method.

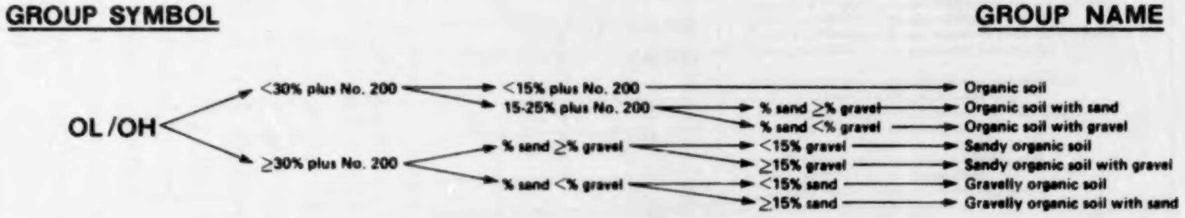


Figure 3-3.—Flow chart for organic soils, visual method.

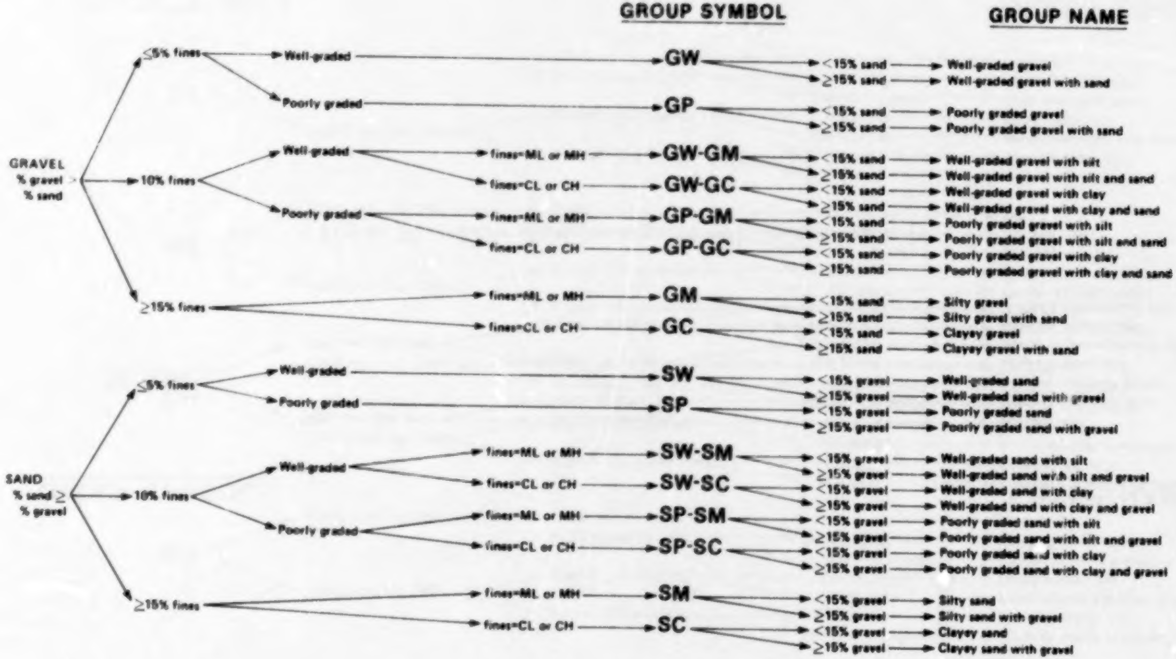

GROUP SYMBOL
GROUP NAME
GRAVEL
% gravel >
% sand
≤5% fines
Well-graded
Poorly graded
10% fines
Well-graded
Poorly graded
≥15% fines
fines=ML or MH
fines=CL or CH
GW
GP
GW-GM
GW-GC
GP-GM
GP-GC
GM
GC
<15% sand
≥15% sand
Well-graded gravel
Well-graded gravel with sand
Poorly graded gravel
Poorly graded gravel with sand
Well-graded gravel with silt
Well-graded gravel with silt and sand
Well-graded gravel with clay
Well-graded gravel with clay and sand
Poorly graded gravel with silt
Poorly graded gravel with silt and sand
Poorly graded gravel with clay
Poorly graded gravel with clay and sand
Silty gravel
Silty gravel with sand
Clayey gravel
Clayey gravel with sand
SAND
% sand ≥
% gravel
≤5% fines
10% fines
≥15% fines
SW
SP
SW-SM
SW-SC
SP-SM
SP-SC
SM
SC
<15% gravel
≥15% gravel
Well-graded sand
Well-graded sand with gravel
Poorly graded sand
Poorly graded sand with gravel
Well-graded sand with silt
Well-graded sand with silt and gravel
Well-graded sand with clay
Well-graded sand with clay and gravel
Poorly graded sand with silt
Poorly graded sand with silt and gravel
Poorly graded sand with clay
Poorly graded sand with clay and gravel
Silty sand
Silty sand with gravel
Clayey sand
Clayey sand with gravel

Figure 3-4.—Flow chart for coarse-grained soils, visual method.

Table 3-1. – Basic group names, primary groups.

Coarse-grained soils	Fine-grained soils
GW – Well graded gravel	CL – Lean clay
GP – Poorly graded gravel	ML – Silt
GM – Silty gravel	OL – Organic clay (on or above A-line) organic silt (below A-line)
GC – Clayey gravel	CH – Fat clay
SW – Well graded sand	MH – Elastic silt
SP – Poorly graded sand	OH – Organic clay (on or above A-line) organic silt (below A-line)
SM – Silty sand	
SC – Clayey sand	

Basic group name—hatched area on Plasticity Chart (Laboratory Classification)

CL-ML – Silty clay
GC-GM – Silty, clayey gravel
SC-SM – Silty, clayey sand

Table 3-2. – Basic group names, 5 to 12 percent fines laboratory criteria.

GW-GM	Well graded gravel with silt
GW-GC	Well graded gravel with clay (if fines = CL-ML) Well graded gravel with silty clay
GP-GM	Poorly graded gravel with silt
GP-GC	Poorly graded gravel with clay (if fines = CL-ML) Poorly graded gravel with silty clay
SW-SM	Well graded sand with silt
SW-SC	Well graded sand with clay (if fines = CL-ML) Well graded sand with silty clay
SP-SM	Poorly graded sand with silt
SP-SC	Poorly graded sand with clay (if fines = CL-ML) Poorly graded sand with silty clay

symbol should be for a coarse-grained soil with fines and the other for a fine-grained soil. For example: GM/ML, CL/SC.

A borderline symbol may be used when the percentage of sand and the percentage of gravel is estimated to be about the same (45-55 percent for visual classification). For example: GP/SP, SC/GC, GM/SM. It is practically impossible to have a soil that would have a borderline symbol of GW/SW. However, a borderline symbol may be used when the soil could be either well graded or poorly graded. For example: GW/GP, SW/SP.

A borderline symbol may be used when the soil could either be a silt or a clay. For example: CL/ML, CH/MH, SC/SM.

A borderline symbol may be used when a fine-grained soil has properties indicating it is at the boundary between a soil of low compressibility and a soil of high compressibility. For example: CL/CH, MH/ML.

The order of the borderline symbol should reflect similarity to surrounding or adjacent soils. For example: soils in a borrow area have been identified as CH. One sample is considered to have borderline symbol of CL and CH. To show similarity to the adjacent CH soils, the borderline symbol should be CH/CL.

The group name for a soil with a borderline symbol should be the group name for the first symbol, except for:

CL/CH – lean to fat clay
ML/CL – clayey silt
CL/ML – silty clay

Preparation for Identification and Classification

A sample composed primarily of vegetable tissue in various stages of decomposition and which has a fibrous to amorphous texture, usually a dark-brown to black color and an organic odor, should be identified as a highly organic soil and shall be classified as peat, PT. Organic plant forms may or may not be readily recognized. In general, the greater the organic content, the greater the water content, void ratio, and compressibility of peat. Materials identified as peat are not subjected to the identification procedures described hereafter.

Soil identification procedures are based on the minus 3-in (75-mm) particle sizes. All plus 3-in (75-mm) particle must be removed, manually, for a loose sample, or mentally, for an intact sample before classifying the soil. Estimate and note the percent by volume of the plus 3-in (75-mm) particles, both the percentage of cobbles and the percentage of boulders.

> Note: Because the percentages of the particle-size distribution in laboratory classification (ASTM: D 2487) are by dry weight and the estimates of percentages for gravel, sand, and fines are by dry weight, it is recommended the description state that the percentages of cobbles and boulders are by volume, not weight, for visual classification.

Of the fraction of the soil smaller than 3 in (75-mm), estimate and note the percentage, by dry weight, of the gravel, sand, and fines. The percentages shall be estimated to the closest 5 percent. The percentages of gravel, sand, and fines must add up to 100 percent, excluding trace amounts. If one of the components is present but not in sufficient quantity to be considered 5 percent in the minus 3-in (75-mm) portion, indicate its presence by the term "trace". For example: trace of fines. A trace is not to be considered in the total of 100 percent for the components.

The first step in the identification procedure is to determine the percentages of fine-grained and coarse-grained materials in the sample. The soil is fine grained if it contains 50 percent or more fines. The soil is coarse grained if it contains less than 50 percent fines. Procedures for the description and classification of these two preliminary identifications follows.

Procedures and Criteria for Classifying Fine-grained Soils

Select a representative sample of the material for examination and remove particles larger than the No. 40 sieve (medium sand and larger) until a specimen equivalent to about a handful of representative material is available. Use this specimen for performing the identification tests which follow.

Identification Criteria for Fine-Grained Soils.—The various tests for identifying properties of fines are dry strength, dilatancy, toughness, and plasticity.

1. Dry strength.—From the specimen, select enough material to mold into a ball about 1 in (25–mm) in diameter. Mold the material until it has the consistency of putty, adding water if necessary. From the molded material, make at least three test specimens. Each test specimen shall be a ball of material about 1/2 in (15-mm) in diameter. Allow the test specimens to dry in air or sun, or dry by artificial means, as long as the temperature does not exceed 60 °C. If the test specimen contains natural dry lumps, those that are about 1/2 in (15-mm) in diameter may be used in place of molded balls. (The process of molding and drying usually produces higher strengths than are found in natural dry lumps of soil). Test the strength of the dry balls or lumps by crushing them between the fingers and note the strength as none, low, medium, high, or very high according to the criteria in table 3-3. If natural dry lumps are used, do not use the results of any of the lumps that are found to contain particles of coarse sand.

The presence of high-strength, water-soluble cementing materials, such as calcium carbonate, may cause exceptionally high dry strengths. The presence of calcium carbonate can usually be detected from the intensity of the reaction with dilute hydrocloric acid. Criteria for reaction to HCl are presented in a subsequent paragraph.

2. Dilatancy.—From the specimen, select enough material to mold into a ball about 1/2 in (15-mm) in diameter. Mold the material, adding water if necessary, until it has a soft, but not sticky, consistency. Smooth the soil ball in the palm of one hand with the blade of a knife or spatula. Shake horizontally, striking the side of the hand vigorously against the other hand several times.

Note the reaction of the water appearing on the surface of the soil. Squeeze the sample by closing the hand or pinching the soil between the fingers and note reaction as none, slow, or rapid according to the criteria in table 3-4. The reaction criteria are the speeds with which water appears while shaking and disappears while squeezing.

Table 3-3. – Criteria for describing dry strength.

None	The dry specimen crumbles with mere pressure of handling.
Low	The dry specimen crumbles with some finger pressure.
Medium	The dry specimen breaks into pieces or crumbles with considerable finger pressure.
High	The dry specimen cannot be broken with finger pressure. Specimen will break into pieces between thumb and a hard surface.
Very High	The dry specimen cannot be broken between thumb and a hard surface.

Table 3-4. – Criteria for describing dilatancy.

None	No visible change in the specimen.
Slow	Water slowly appears on the surface of the specimen during shaking and does not disappear or disappears slowly upon squeezing.
Rapid	Water quickly appears on the surface of the specimen during shaking and disappears upon squeezing.

3. Toughness.—Following the completion of the dilatancy test, the test specimen is shaped into an elongated pat and rolled by hand on a smooth surface or between the palms into a thread about 1/8 in (3-mm) diameter. (If the sample is too wet to roll easily, it should be spread out into a thin layer and allowed to lose some water by evaporation). Fold the sample threads and reroll repeatedly until the thread crumbles at a diameter of about 1/8 in (3-mm) when the soil is near the plastic limit. Note the pressure required to roll the thread near the plastic limit. Also, note the strength of the thread. After the thread crumbles, the pieces should be lumped together and kneaded until the lump crumbles. Note the toughness of the material during kneading.

Describe the toughness of the thread and lump as low, medium, or high according to the criteria in table 3-5.

4. Plasticity.—On the basis of observations made during the toughness test, describe the plasticity of the material according to the criteria given in table 3-6 and figure 3-5.

After the dry strength dilatency, toughness and plasticity tests have been performed, decide on whether the soil is an organic or an inorganic fine-grained soil.

Table 3-5. – Criteria for describing toughness.

Low	Only slight pressure is required to roll the thread near the plastic limit. The thread and the lump are weak and soft.
Medium	Medium pressure is required to roll the thread to near the plastic limit. The thread and the lump have medium stiffness.
High	Considerable pressure is required to roll the thread to near the plastic limit. The thread and the lump have very high stiffness.

Table 3-6. – Criteria for describing plasticity.

Nonplastic	A 3-mm thread cannot be rolled at any water content.
Low	The thread can barely be rolled, and the lump cannot be formed when drier than the plastic limit.
Medium	The thread is easy to roll, and not much time is required to reach the plastic limit. The thread cannot be rerolled after reaching the plastic limit. The lump crumbles when drier than the plastic limit.
High	It takes considerable time rolling and kneading to reach the plastic limit. The thread can be rolled several times after reaching the plastic limit. The lump can be formed without crumbling when drier than the plastic limit.

Classification of Inorganic Fine-Grained Soils.—Using the results of the manual tests and the identifying criteria shown in table 3-7, classify the soils.

Lean clay (CL).—Classify the soil as LEAN CLAY if the soil has medium to high dry strength, no or slow dilatancy, and medium toughness and plasticity.

Fat clay (CH).—Classify the soil as FAT CLAY if the soil has high to very high dry strength, no dilatancy, and high toughness and plasticity.

Silt (ML).—Classify the soil as SILT, if the soil has no to low dry strength, slow to rapid dilatancy, and low toughness and plasticity or is nonplastic.

Elastic silt (MH).—Classify the soil as an ELASTIC SILT if the soil has low to medium dry strength, no to slow dilatancy, and low to medium toughness and plasticity.

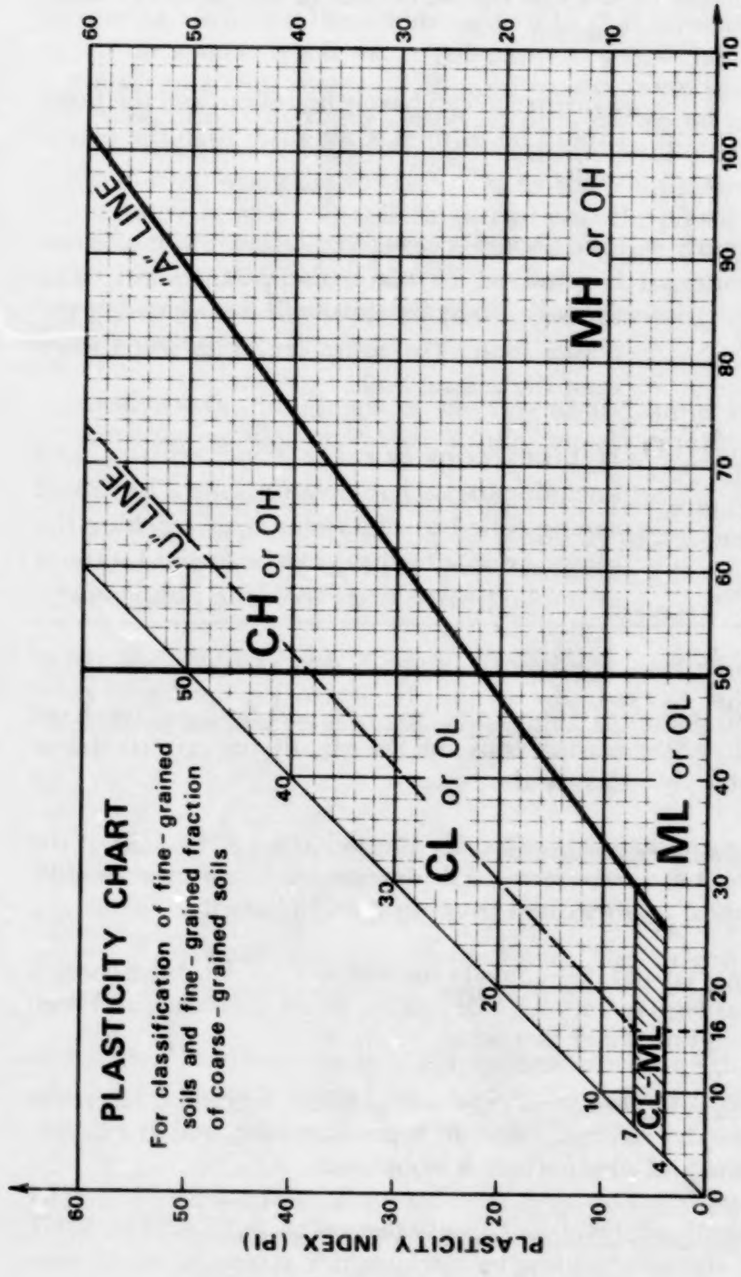


Figure 3.5—Plasticity chart.

Table 3-7. – Identification of inorganic fine-grained soils from manual tests.

Group symbol	Dry strength	Dilatancy	Toughness
ML	None to low	Slow to rapid	Low or thread cannot be formed
CL	Medium to high	None to slow	Medium
MH	Low to medium	None to slow	Low to medium
CH	High to very high	None	High

The properties of an elastic silt are similar to those for a lean clay. However, the silt will dry quickly on the hand and have a smooth, silky feel when dry. Some soils which one would classify as MH according to the field classification criteria are difficult to distinguish from lean clays, CL. It may be necessary to perform laboratory testing to ensure proper classification.

Classification of Organic Fine-Grained Soils.—Classify the soil as an organic soil, OL or OH, if the soil contains enough organic particles to influence the soil properties. Organic soils usually have a dark brown to black color and may have an organic odor. Often organic soils will change color, e.g., black to brown, when exposed to the air. Organic soils would normally not have a high toughness or plasticity. The thread for the toughness test will be spongy. In some cases, through practice and experience, it may be possible to further identify the organic soils as organic silts or organic clays, OL or OH. Correlations between the dilatancy, dry strength, and toughness tests with laboratory tests can be made to classify organic soils in similar materials.

Modifiers for Fine-Grained Soil Classifications.—Based on Visual Observation the soil is estimated to have 15 to 25 percent sand and/or gravel, the words "with sand and/or gravel" shall be added to the group name. Refer to figures 3-2 and 3-3. For example: LEAN CLAY WITH SAND, (CL); SILT WITH SAND AND GRAVEL (ML).

If the Visual Observation of the soil is estimated to be 30 percent or more sand and/or gravel, the words "sandy" or "gravelly" shall be added to the group name. Add the word "sandy" if there appears to be more sand than gravel. Add the word "gravelly" if there appears to be more gravel than sand. Refer to figures 3-2 and 3-3. For example: SANDY LEAN CLAY (CL); GRAVELLY FAT CLAY (CH); SANDY SILT (ML). Note that the Laboratory Classification follows different criteria.

Procedures and Criteria for Classifying Coarse-Grained Soils

A representative sample containing less than 50 percent fines is identified as a coarse-grained soil.

The soil is a gravel if the percentage of gravel is estimated to be more than the percentage of sand by weight.

The soil is a sand if the percentage of gravel is estimated to be equal to or less than the percentage of sand by weight.

The soil is identified as a clean gravel or clean sand if the percentages of fines is estimated to be 5 percent or less. If it is a clean gravel or sand, it is further classified by its gradations.

The soil is classified as a WELL GRADED GRAVEL (GW), or as a WELL GRADED SAND (SW), if it has a wide range of particle sizes and substantial amounts of the intermediate particle sizes. The soil is classified as a POORLY GRADED GRAVEL (GP), or as a POORLY GRADED SAND (SP), if it consists predominantly of one size (uniformly graded) or it has a wide range of sizes with some intermediate sizes obviously missing (gap or skip graded).

The soil is identified as either gravel with fines or sand with fines if the percentage of fines is estimated to be 15 percent or more.

Classify the soil as a CLAYEY GRAVEL (GC), or a CLAYEY SAND (SC), if the fines are clayey as determined by the procedures for fine-grained soil identification.

Identify the soil as a SILTY GRAVEL (GM), or a SILTY SAND (SM), if the fines are silty as determined by the procedures for fine-grained soil identification.

If the soil is estimated to contain 10 percent fines (5 to 15 percent for visual classification), give the soil a dual classification using two group symbols. The first group symbol shall correspond to a clean gravel or sand (GW, GP, SW, SP), and the second symbol shall correspond to a gravel or sand with fines (GC, GM, SC, SM). The typical name shall correspond to the first group symbol plus "with clay" or "with silt" to indicate the plasticity characteristics of the fines. Refer to figure 3-4. For example: WELL GRADED GRAVEL WITH CLAY (GW-GC); POORLY GRADED SAND WITH SILT (SP-SM).

If the specimen is predominantly sand or gravel but contains an estimated 15 percent or more of the other coarse-grained constituent, the words "with gravel" or "with sand" shall be added to the group name. Refer to figure 3-4. For example: POORLY GRADED GRAVEL WITH SAND (GP); CLAYEY SAND WITH GRAVEL (SC).

If the field sample contained any cobbles and/or boulders, the words "with cobble" or "with cobbles and boulders" shall be added to the group name. For example: SILTY GRAVEL WITH COBBLES (GM).

Description of the Physical Properties of Soil

Descriptive information for classification and reporting soil properties—such as angularity, shape, color, moisture conditions, consistency—are presented in the following paragraphs.

Angularity

Describe the angularity of the sand (coarse sizes only), gravel, cobbles, and boulders, as angular, subangular, subrounded, or rounded as indicated by the criteria in table 3-8. A range of angularity may be stated, such as: subrounded to rounded.

Table 3-8. – Criteria for describing angularity of coarse-grained particles.

Angular	Particles have sharp edges and relatively planar sides with unpolished surfaces.
Subangular	Particles are similar to angular description but have rounded edges.
Subrounded	Particles have nearly planar sides but have well-rounded corners and edges.
Rounded	Particles have smoothly curved sides and no edges.

Shape

Describe the shape of the gravel, cobbles, and boulders as flat, elongated, or flat and elongated if they meet the criteria in table 3-9. Otherwise, do not mention. Indicate the fraction of the particles that have the shape, such as: one-third of gravel particles are flat.

Table 3-9. – Criteria for describing particle shape.

The particle shape shall be described as follows where length, width, and thickness refer to the greatest, intermediate, and least dimensions of a particle, respectively.

Flat	Particles with $\frac{\text{width}}{\text{thickness}} > 3$
Elongated	Particles with $\frac{\text{length}}{\text{width}} > 3$
Flat and elongated	Particles meet criteria for both flat and elongated

Color

Color is an important property in identifying organic soils, and within a given locality it may also be useful in identifying materials of similar geologic units. Color should be described for moist samples. If color represents a dry condition, this should also be so stated. If the sample contains layers or patches of varying colors, this should be noted and representative colors should be described. The Munsel Color System is strongly recommended.

Odor

Describe the odor if organic or unusual. Soils containing a significant amount of organic material usually have a distinctive odor of decaying vegetation. This is especially apparent in fresh samples, but if the samples are dried, the odor often may be revived by heating a moistened sample. If the odor is unusual, such as a petroleum product or other chemical, it shall be described and identified if known.

Moisture Conditions

Describe the moisture condition as dry, moist, or wet, as indicated by the criteria in table 3-10.

Table 3-10. – Criteria for describing moisture condition.

Dry	Absence of moisture, dusty, dry to the touch
Moist	Damp but no visible water
Wet	Visible free water, usually soil is below water table

Reaction with HCl

Describe the reaction with HCl as none, weak, or strong, as indicated by the criteria in table 3-11. Since calcium carbonate is a common cementing agent, a report of its presence on the basis of the reaction with dilute hydrochloric acid is important.

Table 3-11. – Criteria for describing reaction with HCl.

None	No visible reaction
Weak	Some reaction, with bubbles forming slowly
Strong	Violent reaction, with bubbles forming immediately

Consistency

Describe consistency (degree of firmness) for intact fine-grained soils as very soft, soft, firm, hard, or very hard, as indicated by the criteria in table 3-12. This observation is inappropriate for soils with significant amounts of gravel.

Table 3-12. – Criteria for describing consistency in fine-grained soils.

Very soft	Thumb will penetrate soil more than 1 in (25-mm)
Soft	Thumb will penetrate soil about 1 in (25-mm)
Firm	Thumb will indent soil about 1/4 in (5-mm)
Hard	Thumb will not indent soil but readily indented with thumbnail
Very hard	Thumbnail will not indent soil

Cementation

Describe the cementation of intact coarse-grained soils as weak, moderate, or strong, as indicated by the criteria in table 3-13.

Structure (fabric)

Describe the structure of the soil being observed. The descriptors presented are for soils only, they are not synonymous with descriptors for rock.

Table 3-13. – Criteria for describing cementation.

Weak	Crumbles or breaks with handling or little finger pressure
Moderate	Crumbles or breaks with considerable finger pressure
Strong	Will not crumble or break with finger pressure

Stratified	– Alternating layers of varying material or color; note thicknesses.
Laminated[1]	– Alternating layers of varying material or color with layers less than 6 mm thick; note thicknesses.
Fissured[1]	– Breaks along definite planes with little resistance to fracturing.
Slickensided[1]	– Fracture planes appear polished or glossy, sometimes striated.
Blocky[1]	– Cohesive soil that can be broken down into small angular lumps which resist further breakdown.
Lenses	– Inclusion of small pockets of different soils, such as small lenses of sand scattered through a mass of clay; note thicknesses.
Homogeneous	– Same color and textural or structural appearance throughout.

Particle Sizes

For gravel and sand components, describe the range of particle sizes within each component as defined in the previous terminology paragraph. Descriptive terms, sizes and examples of particle sizes are shown in table 3–14.

---

[1] Do not use for coarse-grained soils (except fine sands can be laminated).

Table 3-14. – Particle sizes.

Descriptive term	Size	Familiar example within the size range
Boulder	300 mm or more	Larger than basketball[1]
Cobble	300 mm to 75 mm	Grapefruit – orange – volleyball
Coarse gravel	75 mm to 20 mm	Tennis ball – grape
Fine gravel	20 mm to No. 4 sieve (5 mm)	Pea
Coarse sand	No. 4 sieve to No. 10 sieve	Ice cream salt
Medium sand	No. 10 sieve to No. 40 sieve	Openings in window screen
Fine sand	No. 40 sieve to No. 200 sieve	Sugar – table salt

Describe the maximum particle size found in the sample. For reporting maximum particle size, use the following descriptors and size increments:

Fine sand
Medium sand
Coarse sand
5-mm increments from 5 mm to 50 mm
25-mm increments from 50 mm to 300 mm
100-mm increments over 300 mm

For example: "maximum particle size 35 mm"
"maximum particle size 400 mm"

If the maximum particle size is a sand size, describe as fine, medium, or coarse sand. For example: maximum particle size, medium sand.

If the maximum particle size is a gravel size, describe the maximum particle size as the smallest sieve opening that the particle would pass.

If the maximum particle size is a cobble or boulder size, describe the maximum dimension of the largest particle.

Particle Hardness

Describe the hardness of coarse sand and larger particles as hard or state what happens when the particles are hit by a hammer, e.g., gravel-size particles fracture with considerable hammer blow, some gravel-size particles crumble with hammer blow. Hard means particles do not fracture or crumble when struck with a hammer. Remember that the larger the particle, the harder the blow required to fracture it. A good practice is to describe the particle size that was used to ascertain the hardness.

Additional Descriptive Information

Additional descriptive information may include unusual conditions, geological interpretation, or other classification methods, such as:

> Unusual conditions such as presence of roots or root holes, or other organic material or debris;
>
> Degree of difficulty in drilling or augering hole, or excavating a pit; or
>
> Raveling or caving or the trench, hole, pit or exposure; or the presence of mica should be provided.

A local or commercial name and/or a geologic interpretation shall be provided for the soil except for earth dam borrow.

A classification or identification of the soil according to other classification systems may be added if identified as such.

Narrative Descriptions and Examples

The description shall include the information shown in table 3-15, which is a checklist for the description of soils. Example descriptions follow, and additional examples are provided in Chapters 12 and 13 which pertain to logging format and descriptions for Reclamation logs.

Table 3-15. – Checklist for the description of soil classification and identification.

1. Group name and symbol
2. Percent gravel, sand, and/or fines
3. Percent by volume of cobbles and boulders
4. Particle size
5. Particle angularity
6. Particle shape
7. Maximum particle size or dimension
8. Hardness of coarse sand and larger particles
9. Plasticity of fines
10. Dry strength
11. Dilatancy
12. Toughness
13. Color
14. Odor
15. Moisture
16. Reaction with HCl

In-place conditions:

1. Consistency (fine-grained soils only)
2. Cementation
3. Structure
4. Geologic interpretation and/or local name if any
5. Additional comments and description

Example 1: CLAYEY GRAVEL WITH SAND AND COBBLES (GC)—Approximately 50% fine to coarse, subrounded to subangular gravel, approximately 30% fine to coarse, subrounded sand, approximately 20% fines with medium plasticity, high dry strength, no dilatancy, medium toughness; weak reaction with HCl; original field sample had about 5% (by volume) subrounded cobbles, maximum size 150 mm.

IN-PLACE CONDITIONS: firm, homogeneous, dry, brown.

GEOLOGIC INTERPRETATION: alluvial fan.

Example 2: WELL GRADED GRAVEL WITH SAND (GW)—Approximately 75% fine to coarse, hard, subangular gravel, approximately 25% fine to coarse, hard, subangular sand; trace of fines; maximum size 75 mm, brown, dry; no reaction with HCl.

Example 3: SILTY SAND WITH GRAVEL (SM)—Approximately 60% predominantly fine sand, approximately 25% silty fines with low plasticity, low dry strength, rapid dilatancy, and low toughness; approximately 15% fine, hard, subrounded gravel, a few gravel-size particles fractured with hammer blow; maximum size 25 mm; no reaction with HCl. Note—field sample size smaller than recommended.

IN-PLACE CONDITIONS: firm, stratified and contains lenses of silt 1- to 2-in. thick, moist, brown to gray; in-place density was 106 lb/ft^3 and in-place moisture was 9 percent.

Example 4: ORGANIC SOIL (OL/OH)—Approximately 100% fines with low plasticity, slow dilatancy, low dry strength, and low toughness; wet, dark brown, organic odor, weak reaction with HCl.

Example 5: SILTY SAND WITH ORGANIC FINES (SM)—Approximately 75% fine to coarse, hard, subangular reddish sand, approximately 25% organic and silty dark-brown nonplastic fines with no dry strength and slow dilatancy; wet; maximum size, coarse sand; weak reaction with HCl.

Example 6: POORLY GRADED GRAVEL WITH SILT, SAND, COBBLES AND BOULDERS (GP-GM)—Approximately 75% fine to coarse, hard, subrounded to subangular gravel; approximately 15% fine, hard, subrounded to subangular sand; approximately 10% silty nonplastic fines; moist, brown; no reaction with HCl; original field sample had approximately 5% (by volume) hard, subrounded cobbles and a trace of hard, subrounded boulders, with a maximum dimension of 450 mm.

Use of Soil Classification as Secondary Identification Methods for Materials Other Than Natural Soils

General

Materials other than natural soils may be classified and their properties identified and described using the same procedures presented in the preceding subsections. The following materials are considered unnatural soils and should not be given primary classification:

Partially lithified or poorly cemented materials

- Shale
- Sandstone
- Claystone
- Siltstone

Processed, manmade, or other materials

- Crushed rock
- Crushed sandstone
- Slag
- Shells

Identification criteria may be used for describing these materials, especially for describing particle sizes and shapes, and identifying those materials which convert to soils after field or laboratory processing. Description format and classification for these materials are discussed individually in the following paragraphs.

Partially Lithified or Cemented Materials

For the partially lithified or poorly cemented materials, it may be necessary to classify the material because the material will be excavated, processed, or manipulated for use as a construction material. When the physical properties are to be determined for these materials for classification, the material must be processed into a soil by grinding or slaking in water (shales, siltstones, conglomerates, poorly indurated ash deposits).

The physical properties and resulting classification describe the soil type as created by the reworking of the original material. Soil classifications can then be used as a secondary identification. However, the classification symbol and group name must be reported within quotation marks on any logs, tables, figures, and in reports. If laboratory tests are performed on these materials, the results must be reported as shown in table 3-16.

An example of a written narrative for either a test pit or auger hole log based on visual classification is as follows:

Symbol	Description
Shale Fragments	3.4 to 7.8 ft. Shale Fragments—Retrieved as 2- to 4-in pieces of shale from power auger hole, dry, brown, no reaction with HCl. After slaking in water for 24 hours, material classified as "SANDY CLAY (CL)"—Approx. 60% fines with high plasticity, high dry strength, no dilatancy and high toughness; approx. 35% fine to medium, hard sand; approx. 5% gravel-size pieces of shale.

Processed or Manmade Materials

Processed, manmade, or other materials are also often used as construction materials, and classification can be used as a secondary identification. However, for these processed materials the group name and classification symbol are to be within quotation marks. If laboratory tests are performed on these materials, the results must be reported as shown in table 3-16.

An example of a written narrative for logs for visual classification is as follows:

Symbol	Description
CRUSHED ROCK	Stockpile No. 3 CRUSHED ROCK—processed gravel and cobbles from P.T. NO. 7; "POORLY GRADED GRAVEL (GP)"—approx. 90% fine hard, angular gravel-size particles; approx. 10% coarse, angular sand-size particles; dry, tan, no reaction with HCl.

Table 3-16. – Sample of test results summary.

7-1720 (10-
Bureau of Reclamation

SI METRIC

SUMMARY OF PHYSICAL PROPERTIES TEST RESULTS (Inplace Density)

PROJECT ______ FEATURE ______

TABLE II-3-16
SHEET 1 OF 1

IDENTIFICATION				PARTICLE-SIZE FRACTIONS IN PERCENT						CONSISTENCY LIMITS			SPECIFIC GRAVITY				INPLACE DENSITY			
				FINES										PLUS NO. 4						
SAMPLE NUMBER	HOLE NUMBER	DEPTH - m	CLASSIFICATION SYMBOL	SMALLER THAN 0.005 mm	0.005 TO 0.074 mm	SAND NO. 200 (0.074 mm) TO NO. 4 (4.75 mm)	GRAVEL NO. 4 (4.75 mm) TO 76.2 mm	COBBLES 76.2 mm TO [illegible] mm	OVERSIZE LARGER THAN [illegible] mm	LIQUID LIMIT - %	PLASTICITY INDEX - %	SHRINKAGE LIMIT - %	MINUS NO. 4	BULK	APPARENT	ABSORPTION - %	DRY DENSITY - kg/m³	WATER CONTENT - %	DEGREE OF SATURATION - %	
	Example 1																			
12	AP-13	4,7-6.2	shale	fragments		(as	received)													
		*	"CL"	53	30	17														
	Example 2																			
13	DH 313-B	27.2-28.7	siltstone			(as	received)										118	18	17	19
		*	"ML"	50	41	9				27	3									
	Example 3																			
14	Commercial	Source	Crushed Sandstone			(as	received)													
			"SP-SM"	5	4	91				22	2									
	Example 4																			
15	DH No. 3		Crushed Rock																	
			"GP"	0	0	11	89													
	Example 5																			
16	Waste Pile 7B		Slag																	
	CF and 1		"GP"	2	1	25	72													

* properties of material after processing in laboratory

NOTE: Numbers in parentheses are metric equivalents of numbers directly above.

GPO [illegible]

TABLE II-3-16 SHEET 1 OF 1

Special Cases for Classification

Some materials that require a classification and description according to USBR 5000 [1] or USBR 5005 [2] should not have a heading that is a classification group name. When these materials will be used in, or influence, design and construction, they should be described according to the criteria for logs of test pits and auger holes and the classification symbol and typical name placed in quotation marks similar to the previous discussion on secondary identification method for materials other than natural soils. The heading should be as follows:

Topsoil
Landfill
Road surfacing
Uncompacted or Compacted Fill

For example:

Classification Symbol	Description
TOPSOIL	0.0 – 2.6 ft. TOPSOIL—would be classified as "ORGANIC SILT (OL)." Approx. 80% fines with low plasticity, slow dilatancy, low dry strength, and low toughness; approx. 20% fines to medium sand; wet, dark brown, organic odor, weak reaction with HCl; roots present throughout.

Some material should be described but not given a classification symbol or group name, such as landfill (trash, garbage, etc.) or asphalt road. All of the above listed terms are only examples; this is not a complete list. If the above materials are not to be used or influence design or construction, only the basic term are listed above may be shown on the logs without a complete description or classification.

Table 3-17. – Soils classification chart.

CRITERIA FOR ASSIGNING GROUP SYMBOLS AND GROUP NAMES USING LABORATORY TESTS [a]				SOIL CLASSIFICATION	
				GROUP SYMBOL	GROUP NAME [b]
COARSE-GRAINED SOILS more than 50% retained on No. 200 sieve	GRAVELS More than 50% of coarse fraction retained on No. 4 sieve	CLEAN GRAVELS Less than 5% fines [c]	$Cu \geq 4$ and $1 \leq Cc \leq 3$ [e]	GW	Well-graded gravel [f]
			$Cu < 4$ and/or $1 > Cc > 3$ [e]	GP	Poorly graded gravel [f]
		GRAVELS WITH FINES More than 12% fines [c]	Fines classify as ML or MH	GM	Silty gravel [f,g,h]
			Fines classify as CL or CH	GC	Clayey gravel [f,g,h]
	SANDS 50% or more of coarse fraction passes No. 4 sieve	CLEAN SANDS Less than 5% fines [d]	$Cu \geq 6$ and $1 \leq Cc \leq 3$ [e]	SW	Well-graded sand [i]
			$Cu < 6$ and/or $1 > Cc > 3$ [e]	SP	Poorly graded sand [i]
		SANDS WITH FINES More than 12% fines [d]	Fines classify as ML or MH	SM	Silty sand [g,h,i]
			Fines classify as CL or CH	SC	Clayey sand [g,h,i]
FINE-GRAINED SOILS 50% or more passes the No. 200 sieve	SILTS AND CLAYS Liquid limit less than 50	inorganic	PI > 7 and plots on or above "A" line [j]	CL	Lean clay [k,l,m]
			PI < 4 or plots below "A" line [j]	ML	Silt [k,l,m]
		organic	$\frac{\text{Liquid limit - oven dried}}{\text{Liquid limit - not dried}} < 0.75$	OL	Organic clay [k,l,m,n] Organic silt [k,l,m,o]
	SILTS AND CLAYS Liquid limit 50 or more	inorganic	PI plots on or above "A" line	CH	Fat clay [k,l,m]
			PI plots below "A" line	MH	Elastic silt [k,l,m]
		organic	$\frac{\text{Liquid limit - oven dried}}{\text{Liquid limit - not dried}} < 0.75$	OH	Organic clay [k,l,m,p] Organic silt [k,l,m,q]
Highly organic soils		Primarily organic matter, dark in color, and organic odor		PT	Peat

a. Based on the material passing the 3-in (75-mm) sieve.
b. If field sample contained cobbles and/or boulders, add "with cobbles and/or boulders" to group name.
c. Gravels with 5 to 12% fines require dual symbols
  GW-GM well-graded gravel with silt
  GW-GC well-graded gravel with clay
  GP-GM poorly graded gravel with silt
  GP-GC poorly graded gravel with clay
d. Sands with 5 to 12% fines require dual symbols
  SW-SM well-graded sand with silt
  SW-SC well-graded sand with clay
  SP-SM poorly graded sand with silt
  SP-SC poorly graded sand with clay

e. $Cu = D_{60}/D_{10}$ $Cc = \frac{(D_{30})^2}{D_{10} \times D_{60}}$

f. If soil contains ≥ 15% sand, add "with sand" to group name.
g. If fines classify as CL-ML, use dual symbol GC-GM, SC-SM.
h. If fines are organic, add "with organic fines" to group name.
i. If soil contains ≥ 15% gravel, add "with gravel" to group name.
j. If the liquid limit and plasticity index plot in hatched area on plasticity chart, soil is a CL-ML, silty clay.
k. If soil contains 15 to 29% plus No. 200, add "with sand" or "with gravel" whichever is predominant.
l. If soil contains ≥ 30% plus No. 200, predominantly sand, add "sandy" to group name.
m. If soil contains ≥ 30% plus No. 200, predominantly gravel, add "gravelly" to group name.
n. PI ≥ 4 and plots on or above "A" line.
o. PI < 4 or plots below "A" line.
p. PI plots on or above "A" line.
q. PI plots below "A" line.

BIBLIOGRAPHY

[1] Bureau of Reclamation, Geotechnical Branch Training Manual No. 4, Denver CO, 1986.

[2] Bureau of Reclamation, Geotechnical Branch Training Manual No. 5, Denver CO, 1986.

[3] U.S. Department of Agriculture, *Agriculture Handbook* No. 436, Appendix I (Soil Taxonomy), December 1975.

[4] Bureau of Reclamation, USBR 3900 Standard Definitions of Terms and Symbols Relating to Soil Mechanics, Denver CO, In preparation.

Chapter 4

CLASSIFICATION OF ROCKS AND THE DESCRIPTION OF PHYSICAL PROPERTIES OF ROCK

Introduction

Uniformity of definitions, descriptors, and identification of rock units is important to maintain continuity in geologic logs, drawings, and reports from a project with multiple drilling sessions, different loggers and mappers. Therefore, all geologists are reminded to record all significant observable parameters when logging or mapping. This chapter presents a system for the identification and classification of rocks and the standard terminology and descriptive criteria for physical properties of engineering significance for rock. The standards presented in this chapter may be expanded or modified, but only if clearly justified and documented.

Rock Classification

Numerous systems are in use for field and petrographic classification of rocks. Many classifications require detailed petrographic laboratory tests and thin sections, while others require limited petrographic examination and field tests. Reclamation has established a classification system which is modified from R. B. Travis [1]. While not based entirely on field tests or field identification of minerals, many of the classification categories are sufficiently broad that field identification is possible. Even where differences in the mineral constituents cannot be determined precisely in the field, they usually are not significant enough to affect the engineering properties of the rock if classified somewhat incorrectly by lithologic name. Detailed mineralogical identification and petrographic classification can be performed on hand samples or core samples submitted to the Denver Office Petrographic Laboratory.

If samples are submitted to the Petrographic Laboratory, the petrographic classification generally will coincide with the classification according to Travis. The petrographic igneous rock classifications are somewhat more detailed to include specialty rock types based upon mineralogical composition, texture, and occurrence. For example, a lamprophyric dike composed of green hornblende phenocrysts or clinopyroxene in the groundmass could be classified as spessartite, whereas a lamprophyre containing biotite with or without clinopyroxene could be classified as a kersantite. Sedimentary rock classifications generally include grain size, type of cement or matrix, mineralogical composition greater than 15 percent in order of decreasing to increasing amounts, and the rock type, such as medium-grained, calcite-cemented, feldspathic-quartzose sandstone, and coarse- to fine-grained, lithic-feldspathic-quartzose graywacke with an argillaceous-ferruginous-calcareous matrix. Metamorphic rock classifications are more detailed to include specific rock types based upon crystal size, diagnostic accessory minerals, mineralogical composition greater than 15 percent in order of decreasing to increasing amounts, and structure. Two metamorphic examples are medium-grained, hornblende-biotite schist, or fine- to medium-grained, garnetiferous, muscovite-chlorite-feldspar-quartz gneiss. The above classification can be abbreviated by the deletion of mineral names from the left to right as desired, i.e., the mineral type immediately preceding the rock name is the most diagnostic.

Note that Reclamation has restricted the term "quartzite" to denote a metamorphic rock only. The sedimentary sandstone equivalent is termed a "quartz cemented quartzose sandstone."

It is important that samples submitted to the Petrographic Laboratory be representative of the in situ rock unit. For example, if a granitic gneiss is sampled but only the granite portion submitted, the rock will be petrographically classified as a granite since the gneissic portion cannot be observed or substantiated by the thin section and hand specimen, both of which are retained in the Petrographic Laboratory for public inspection and review. Petrographic classifications can be related to the engineering properties of rock units and are important for documentation in the event of contract litigation.

The engineering geologist must remember that geologic rock units should be simple and general rock names which are based on either field identification, existing literature, or detailed petrographic examination as well as engineering properties determined from laboratory testing. Resist overclassification. For example, use "hornblende schist" or "amphibolite" instead of "sericite-chlorite-calcite-hornblende schist." The term "granite" may be used as the rock name and conveys more to the designer than the petrographically correct term "nepheline-syenite porphyry." Detailed mineralogical descriptions may be provided in reports when describing the various rock units and may be required to correlate between observations, but mineralogical classifications are not desirable as a rock unit name unless the mineral constituents or fabric are significant to engineering properties.

The classification for igneous, sedimentary, metamorphic and pyroclastic rocks is shown on figures 4-1, 4-2, 4-3, and 4-4, respectively. These figures are condensed and modified slightly from Travis' classifications, but it is acceptable to use the more detailed original classifications of Travis. Figure 4-5 or appropriate AGI data sheets are suggested for use when estimating percentages of composition to assist in more accurate classification.

Description of Rock

Adequate descriptors, a uniform format, and standard terminology must be used for all Reclamation geologic investigations to describe rock foundation conditions properly to other geologists and designers. These paragraphs provide descriptors for those physical characteristics of rock that are to be used in logs of exploration, in narratives of reports, and on preconstruction geologic maps and cross sections, as well as construction or "as-built" drawings. Alphanumeric descriptors provided are compatible with data-field entries and appropriate columns for the "Rock Properties" computer generated logs. Chapter 5 establishes descriptors for the physical characteristics of discontinuities in rock required for engineering geologic studies.

All descriptors used are to be defined and included in a legend for all data submitted for design and/or records of construction. Reclamation standard drawing 40-D-6493,

	COLOR	LIGHT →						DARK			
	QUARTZ	> 10 %	< 10 %	> 10 %	< 10 %	> 10 %		< 10 %		CHIEFLY PYROXENE AND/OR OLIVINE	SPECIAL TYPES
	FELDSPAR	POTASSIUM FELDSPAR > 2/3 TOTAL FELDSPAR		POTASSIUM FELDSPAR 1/3-2/3 TOTAL FELDSPAR		PLAGIOCLASE > 2/3 TOTAL FELDSPAR					
						K-SPAR > 10 % TOTAL	SODIC PLAGIOCLASE		CALCIC PLAGIOCLASE		
	CHIEF ACCESSORY MINERALS	HORNBLENDE BIOTITE MUSCOVITE		HORNBLENDE BIOTITE PYROXENE		HORNBLENDE, BIOTITE, PYROXENE			PYROXENE OLIVINE	SERPENTINE IRON ORE	
Fine to coarse > 0.1 mm	EQUIGRANULAR Batholiths, lopoliths, stocks, large laccoliths, thick dikes and sills.	GRANITE	SYENITE	QUARTZ MONZONITE	MONZONITE	GRANODIORITE	QUARTZ DIORITE	DIORITE	GABBRO	PERIDOTITE	PEGMATITIE - Very coarse grained, normally silicic, rock (or small irregular mass). APLITE - Fine-grained rock having sugary texture. LAMPROPHYRE - Dark rock with high percentage FeMg materials as phenocrysts and in ground mass.
PORPHYRITIC •	FINE TO COARSE GRAIN GROUND MASS Laccoliths, dikes, sills, plugs, small stocks, margins, of larger masses.	GRANITE PORPHYRY	SYENITE PORPHYRY	QUARTZ MONZONITE PORPHYRY	MONZONITE PORPHYRY	GRANODIORITE PORPHYRY	QUARTZ DIORITE PORPHYRY	DIORITE PORPHYRY	GABBRO PORPHYRY	PERIDOTITE PORPHYRY	
	APHANITIC GROUND MASS Dikes, sills, laccoliths, surface flows, margins of larger masses, welded tuffs.	RHYOLITE PORPHYRY	TRACHYTE PORPHYRY	QUARTZ LATITE PORPHYRY	LATITE PORPHYRY	DACITE PORPHYRY		ANDESITE PORPHYRY	BASALT PORPHYRY	RARE	• TRAP - dark-colored aphanitic rock, • FELSITE - light-colored aphanitic rock.
APHANITIC < 0.1 mm	MICROCRYSTALLINE Dikes, sills, surface flows, margins of larger masses, welded tuffs.	RHYOLITE	TRACHYTE	QUARTZ LATITE	LATITE	DACITE		ANDESITE	BASALT		
	GLASSY Surface flows, margins of dikes and sills, welded tuffs.	OBSIDIAN - dark colored PITCHSTONE - resinous VITROPHYRE - porphyritic PERLITE - concentric fractures PUMICE - light colored, finely vesicular SCORIA - dark colored, coarsely vesicular			Normally it is not possible to determine the compositon of these rocks. They are customarily designated by the names at the left. Basic glass is rare so rocks named, except scoria, will normally be silicic. If the approximate composition (by close association) can be determined, the name may be prefixed by the name of the appropriate aphanitic rock, for example, "trachyte obsidian" or "latite vitrophyre". In general, scoria is basic; basic obsidian is called "tachylite"; and spherulite tachylite is "variolite".						• These are somewhat vague terms and generally should not be used.

• The names in these rows should be used if there are >50% phenocrysts. If there are < 50% phenocrysts, the adjective "porphyritic" should be used, for example, "porphyritic granite".

Figure 4-1.—Field classification of igneous rocks (modified after R. B. Travis [1955]).

TEXTURE →		GRAIN SIZE <0.0625 mm			GRAIN SIZE 0.0625 - 2 mm						GRAIN SIZE >2 mm	
		CRYSTALLINE, CLASTIC, AMORPHOUS, BIOCLASTIC, ETC.			CLASTIC						CLASTIC	
COMPOSITION OF MAJOR FRACTION →		CLAY MINERALS or Clay-size Materials	Composition as indicated in left column	CHIEFLY CALCITE OR DOLOMITE	CHIEFLY QUARTZ	QUARTZ with 10-25% FELDSPAR	QUARTZ with >10% ROCK FRAGMENTS	QUARTZ with >25% FELDSPAR	QUARTZ FELDSPAR ROCK FRAGMENTS	PYROCLASTICS	CHIEFLY ONE CONSTITUENT Homogeneous breccias and conglomerates	SEVERAL CONSTITUENTS Mixed breccias and conglomerates
COMPOSITION OF MINOR FRACTION	<10 % MINOR FRACTION			LIMESTONE, DOLOMITE, ETC.	QUARTZOSE SANDSTONE	FELDSPATHIC SANDSTONE	LITHIC SANDSTONE	ARKOSE	GRAYWACKE	Refer to Figure II-4-4 for classification of Pyroclastics	Name consists of chief constituent and size, as QUARTZ COBBLE CONGLOMERATE, LIMESTONE PEBBLE BRECCIA, ETC.	Name consists of "mixed" and size, as MIXED BOULDER BRECCIA. Name may include composition as ANDESITE-CHERT-ARKOSE CONGLOMERATE
	CLAY MINERALS or Clay-size materials	CLAYSTONE, SILTSTONE - nonfissile SHALE - fissile ARGILLITE - highly indurated BENTONITE - sodium montmorillinite		ARGILLACEOUS LIMESTONE, MARL, ETC.	ARGILLACEOUS QUARTZOSE SANDSTONE	ARGILLACEOUS FELDSPATHIC SANDSTONE	ARGILLACEOUS LITHIC SANDSTONE	ARGILLACEOUS ARKOSE	ARGILLACEOUS GRAYWACKE		ARGILLACEOUS (SIZE) CONGLOMERATE	ARGILLACEOUS MIXED CONGLOMERATE, GLACIAL TILL, FANGLOMERATE
	SILICA OPAL CHALCEDONY QUARTZ CHERT	SILICEOUS SHALE, SILCEOUS CLAYSTONE, ETC.	DIATOMITE, RADIOLARITE, SILICEOUS OOLITE, OOLITE CHERT,	SILICEOUS LIMESTONE, CHERTY LIMESTONE, ETC.	SILICEOUS QUARTZOSE SANDSTONE	SILICEOUS FELDSPATHIC SANDSTONE	SILICEOUS LITHIC SANDSTONE	SILICEOUS ARKOSE	SILICEOUS GRAYWACKE		SILICEOUS (SIZE) CONGLOMERATE	SILICEOUS MIXED (SIZE) CONGLOMERATE
	CALCITE OR DOLOMITE	CALCAREOUS SHALE, ETC.	LIMESTONE DOLOMITE CALICHE - lime-rich deposit formed near surface OOLITE LIMESTONE FOSSILIFEROUS LIMESTONE CHALK CLASTIC LIMESTONE		CALCAREOUS QUARTZOSE SANDSTONE	CALCAREOUS FELDSPATHIC SANDSTONE	CALCAREOUS LITHIC SANDSTONE	CALCAREOUS ARKOSE	CALCAREOUS GRAYWACKE		CALCAREOUS (SIZE) CONGLOMERATE	CALCAREOUS MIXED (SIZE) CONGLOMERATE

Rocks including significant quantities of iron, carbon, or miscellaneous salts follow the above format. For example: ferruginous quartzose sandstone, coal, carbonaceous shale, gypsum, phosphatic limestone.

Figure 4-2.—Field classification of sedimentary rocks (modified after R. B. Travis [1955]).

COLOR	CHIEF MINERALS	ACCESSORY MINERALS	NONDIRECTIONAL STRUCTURE (MASSIVE OR GRANULOSE)		DIRECTIONAL STRUCTURE (LINEATED OR FOLIATED)					
			CONTACT METAMORPHISM		MECHANICAL METAMORPHISM	REGIONAL METAMORPHISM HIGHLY FOLIATED ←→ LESS FOLIATED				PLUTONIC METAMORPHISM
			FINE	FINE TO COARSE	CATACLASTIC	SLATY	PHYLLITIC	SCHISTOSE	GNEISSOSE	MIGMATITIC
						APHANITIC	FINE	FINE TO COARSE		
LIGHTER ↑	FELDSPAR	ACTINOLITE ALBITE ANDALUSITE ANTHOPHYLLITE BIOTITE CHIASTOLITE CHLORITE CHLORITIOD CORDIERITE DIOPSIDE ENSTATITE EPIDOTE GARNET GLAUCOPHANE GRAPHITE KYANITE MUSCOVITE OLIVINE PYROPHYLLITE PHLOGOPITE SCAPOLITE SERICITE SERPENTINE SILLIMANITE STAUROLITE TOURMALINE TREMOLITE WOLLASTONITE	HORNFELS	METAQUARTZITE	These rocks are formed by crushing with only minor recrystallization CATACLASITE Nondirectional MYLONITE Foliated, aphanitic PHYLLONITE Foliated, fine grain, resembles a phyllite. FLASER GRANITE, FLASER DIORITE, FLASER CONGLOMERATE ETC. - Flaser structure, lenses and layers of original or relatively unaltered granular minerals surrounded by matrix of highly sheared and crushed material. AUGEN GNEISS - Augen structure	SLATE	PHYLLITE	SCHIST (AMPHIBOLITE)	GNEISS AUGEN GNEISS	These rocks have a gneissose, streaked, or irregular structure produced by intimate mixing of metamorphic and magmatic materials. When they can be recognized as "mixed rock", they are called migmatite gneiss. They may originate by injection (injection migmatite, injection gneiss, or lit-par-lit gneiss), or by differential fusion. Many so-called migmatites probably originate by partial granitization or by metamorphic differentiation. But at great depth these processes apparently do not differ substantially from the igneous processes forming migmatite, so the products are usually indistinguishable. Migmatities are named by prefixing the rock name of the granitic material to the appropriate root as "granite migmatite", "monzonite injection migmatite", etc.
	QUARTZ									
↓	MICA			AMPHIBOLITE						
DARKER	HORNBLENDE									
	CHLORITE									
	ACTINOLITE									
	TREMOLITE							GNEISSIC SCHIST		
LIGHTER ↑	TALC			SOAPSTONE					SCHISTOSE GNEISS	
	CALCITE AND/OR DOLOMITE			MARBLE						
↓	CALC-SILICATES			SKARN						
DARKER	SERPENTINE			SERPENTINITE				SERPENTINITE		

Naming a metamorphic rock consists chiefly of prefixing the structural term with mineral names or an appropriate rock name. The rock name indicates either the original rock, if recognizable, or the new mineral composition. The prefix "meta", as "Metagabbro", "metasandstone", "metatuff", etc., is applied to rocks that have undergone considerable recrystallization but have largely retained their original fabric. Most of the minerals listed as accessories are genetically important and if present should be included in the rock name regardless of their quantity.

Figure 4-3.—Field classification of metamorphic rocks (modified after R. B. Travis [1955]).

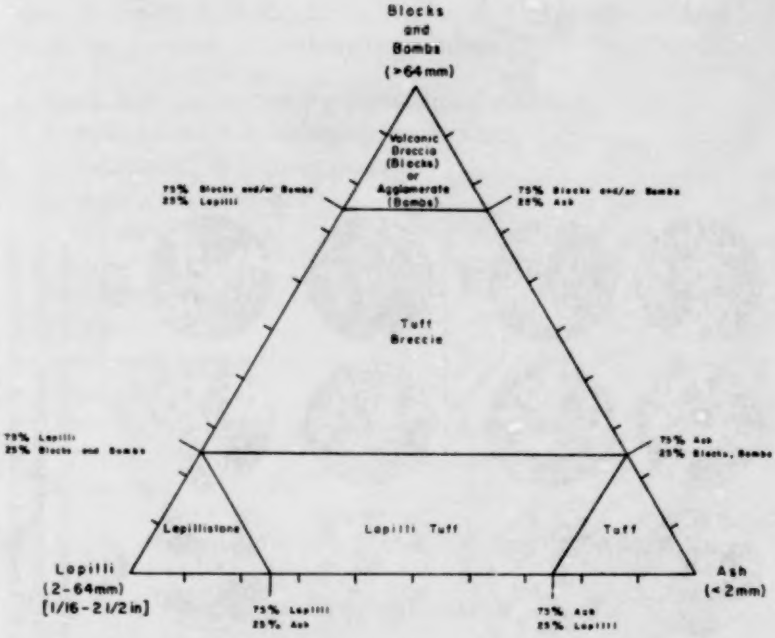

Blocks and Bombs (>64mm)
Volcanic Breccia (Blocks) or Agglomerate (Bombs)
75% Blocks and/or Bombs 25% Lapilli
75% Blocks and/or Bombs 25% Ash
Tuff Breccia
75% Lapilli 25% Blocks and Bombs
75% Ash 25% Blocks, Bombs
Lapillistone
Lapilli Tuff
Tuff
Lapilli (2-64mm) [1/16-2 1/2 in]
Ash (<2mm)
75% Lapilli 25% Ash
75% Ash 25% Lapilli

Figure 4-4.—Field classification of pyroclastic rocks. Blocks are angular to subangular clasts > 64mm; bombs are rounded to subrounded clasts > 64mm. Determine percent of each size present (ash, lapilli, blocks, and bombs) and list in decreasing order after rock name. Preceed rock name with the term "welded" for pyroclastic rocks which have retained enough heat to fuse after deposition. Rock names for such deposits will usually be selected from the lower right portion of the classification diagram above. (Modified from Fisher, 1966 [2] and Williams and McBirney, 1979 [3]).

may be used for geologic reports of specifications where the standard descriptors and terminology established for rock are used during data collection. Suitable reproducibles (vellum or mylar) are available upon request from the Geology Branch. [Note: This drawing contains the following tables from this manual: Tables 4-1, 4-2, 4-3, 4-4, 4-5, 4-6, and additional texture adjectives.]

Format for Descriptions of Rock

Engineering geology rock descriptions are to include generalized lithologic and physical characteristics using qualitative and quantitative descriptors. A general format for

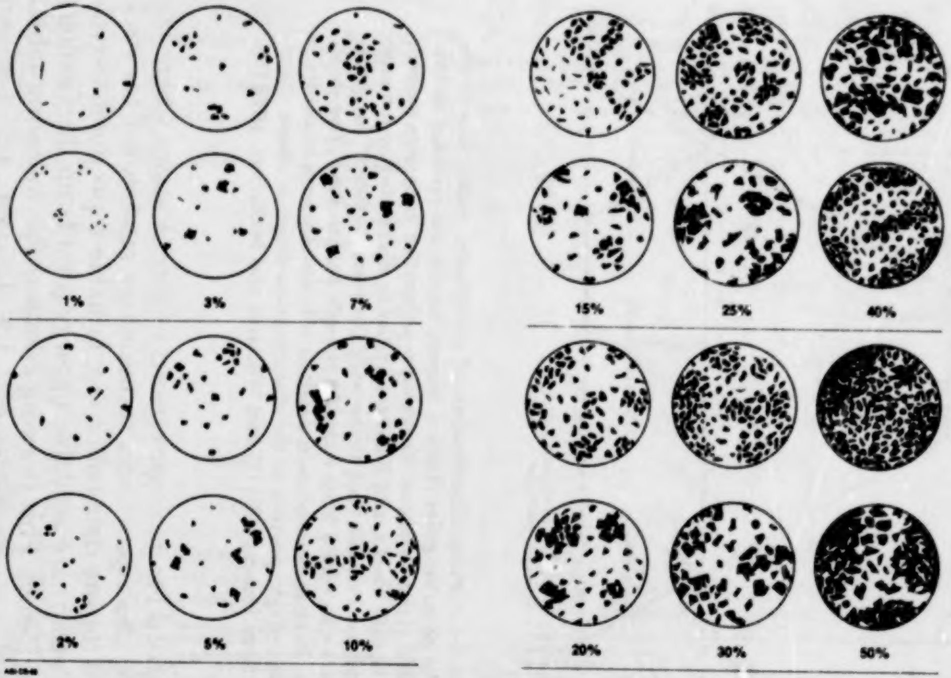


Figure 4-5.—Charts for estimating percentage of composition of rocks and sediments. Prepared by R. D. Terry and G. V. Chilingar for Journal of Sedimentary Petrology, vol. 25, pp. 229-234, 1955. Copied from Robert R. Compton, *Manual of Field Geology*, 3rd edition, pp. 332 to 333, John Wiley and Sons, Inc., New York, 1962 [4].

describing rock in Reclamation logs of exploration and legends on general note drawings follows:

- Rock unit (member or formation) name
- Lithology with lithologic descriptors
    - composition (mineralogy)
    - grain/particle size
    - texture
    - color
- Bedding/foliation/flow texture
- Weathering
- Hardness/strength
- Contacts
- Discontinuities (includes fracture indexes)
- Permeability data (as available from testing)
- Moisture conditions

Example descriptions are presented in a later section.

Rock Unit Names and Identification

Rock unit names not only are required for identification purposes, but may also provide indicators of formation and geologic history, geotechnical characteristics, and correlations with other areas. A simple descriptive name and map symbol should be assigned, so as to provide other users with possible engineering characteristics of the rock type. The rock unit names may be stratigraphic, lithologic, genetic, or a combination of these, such as Navajo Sandstone (Jn), Tertiary shale (Tsh), Jurassic chlorite schist (Jcs), Precambrian granite (p€gr), or metasediments (ms). Bedrock units of similar physical properties should be delineated and identified as to their engineering significance. Every attempt should be made to identify and delineate units as early as possible during each geologic study. For early planning studies, reservoir maps and other large-scale drawings may call for use of geologic formations or groups of engineering geologic units with descriptions of their engineering significance in accompanying discussions. When more detailed mapping is performed, each unit should be individually identified and delimited.

Where significant and possible to do so, units are to be differentiated by engineering properties and not necessarily formal stratigraphic units. Although stratigraphic names are not required, bedrock units should be correlated to stratigraphic names in the data report or by an illustration, such as a stratigraphic column. This may require research and consultation to establish proper stratigraphic nomenclature. Stratigraphic names and ages (formation, member) may be used as the rock unit name where descriptive enough to identify rock properties.

For engineering studies, each particular stratigraphic unit may require further subdivisions to identify differing engineering parameters such as susceptibility to weathering or presence of alteration, dominant discontinuity characteristics, hardness and/or strength, deformability, and deleterious minerals or beds (such as swelling susceptibility, sulfates, or clays). For example, a Tertiary shale unit, Tsh, may be differentiated as Tsh_1 or Tsh_2 if unit 2 contains bentonite interbeds and unit 1 does not, and Tsh_c could be used as a unit name for the bentonite beds. A chlorite schist unit, Cs, may be differentiated as Cs_A or Cs_B where unit A contains higher percentages of chlorite or talc and is significantly softer (different deformation properties) than unit B. A metasediment unit, ms, may be further differentiated on more detailed maps and logs as ms_{sh} (shale) or ml_{ls} (limestone). All differentiated units are to be assigned distinctive map symbols and are to be described on the General Geologic Legend, Explanation, and Notes drawings.

Descriptors and Descriptive Criteria for Physical Characteristics of Rock

Lithologic Descriptors (Composition, Grain Size, and Texture).—Provide a brief lithologic description of the rock unit. This includes a general description of mineralogy, degree of induration, cementation, crystal and grain sizes and shapes, textural adjectives, and color. Lithologic descriptors are especially important for the description of engineering geology subunits when rock unit names are not specific, such as metasediments, Tertiary intrusives, or Quaternary volcanics.

1. Composition.—Detailed mineral composition generally is not necessary or desirable unless it is useful in

correlating units or indicating physical properties pertinent to engineering. Use standard adjectives such as sandy, silty, calcareous, etc. Note unique features such as fossils, large crystals, inclusions, concretions, and nodules which may be used as markers for correlations and interpretations.

2. Crystal or Particles Sizes and Shapes.—Describe the typical crystal or grain shapes and provide a description of sizes present in the rock unit based on the following standards:

- Igneous and metamorphic rocks.—Table 4-1 is to be used for descriptions of crystal sizes in igneous and metamorphic rocks. Crystal sizes given in millimeters are preferred rather than fractional-inch equivalents.

- Sedimentary and pyroclastic rocks.—Terminology for particles sizes and their lithified products which form sedimentary and pyroclastic rocks are provided in table 4-2. The size limits do not correspond to Reclamation's classification system for soil particles size, but are to be used for the field description and petrographic classification of rocks. These limits are the accepted sizes in geologic literature and are used by Reclamation's Petrographic Laboratory.

Table 4-1. – Igneous and metamorphic rock grain size descriptors.

Descriptor	Average crystal diameter
Very coarse-grained or pegmatic	>10 mm (7 3/8 in)
Coarse-grained	5-10 mm (3/16 – 3/8 in)
Medium-grained	1-5 mm (1/32 – 3/16 in)
Fine-grained	0.1-1 mm (0.04 – 1/32 in.)
Aphanitic (cannot be seen with the unaided eye)	<0.1 mm (<0.04 in)

Table 4-2. – Sedimentary and pyroclastic rock particle-size descriptors (AGI Glossary).

USCS (soils only) Particle size	Size in mm (inches)	Sedimentary (epiclastic) Rounded, subrounded, subangular		Volcanine (pyroclastic)	
		Particle or fragment	Lithified product	Fragment	Lithified product*
Boulder		Boulder	Boulder conglomerate	Block+	Volcanic breccia+
	300 (12)				
	256 (10)				
Cobble		Cobble	Cobble conglomerate	Bomb	Agglomerat
	75 (3)				
	64 (2.5)				
Coarse gravel		Pebble	Pebble conglomerate		
	32 (1.3)			Lapilli	Lapilli tuff
	20 (0.8)				
Fine gravel					
	4.75 (0.19)				
	4 (0.16)				
Coarse sand		Granule	Granule conglomerate	Coarse ash	Coarse tuff
	2 (0.08)				
Medium sand		Very coarse sand	Sandstone (Very coarse, coarse, medium fine or very fine)		
	1 (0.04)	Coarse sand			
	0.5 (0.02)	Medium sand			
	0.42				
Fine sand	0.25	Fine sand		Fine ash	Fine tuff
	0.125	Very fine sand			
	0.074				
Fines Nonplastic Silt	0.0625	Silt	Siltstone Shale		
	0.00391	Clay	Claystone Shale		
Plastic Clay					

+ Broken from previous igneous rock block shaped (angular to subangular). Solidifed from plastic material while in flight, rounded clasts.

* Refer to figure 4-4

3. Textural adjectives.—In this context, texture is used to describe the arrangements of minerals, grains, or voids. These microstructural features can affect the engineering properties of the rock mass. Use simple, standard, textural adjectives or phrases such as porphyritic vesicular, scoriaceous, pegmatitic, granular, well developed grains, dense, fissile, slaty, or amorphous. Use of terms such as hologyaline, hypidiomorphic granular, and crystaloblastic, is to be avoided.

Textural terms which identify solutioning, leaching, or voids in bedrock are useful for describing primary texture, weathering, alteration, permeability, and density.

The terminology which follows defines sizes of voids, or holes in bedrock. However, when describing pits, vugs, cavities, or vesicles, a complete description which includes the typical diameter, or the "mostly" range, and the maximum size observed is required. For example:

> ". . . randomly oriented, elliptically shaped vugs mostly range from 0.03- to 0.06-ft in diameter, maximum size 0.2 foot; decrease in size away from quartz-calcite vein; about 15 percent contain calcite crystals . . . ."

or

> ". . . cavity, 3.3 ft wide by 16.4 ft long by 2.3 ft high, striking N 45° W, dipping 85° SW was . . . ."

- Pit (pitted)—Pinhole to 0.03 ft [3/8 in] (<1 to 10 mm) openings.

- Vug (vuggy)—Small opening (usually lined with crystals) ranging in diameter from 0.03 ft [3/8 in] to 0.33 ft [4 in] (10 to 100 mm).

- Cavity—An opening larger than 0.33 ft [4 in] (100 mm), size descriptions are required, and adjectives such as small, or large, may be used, if defined.

- Honeycombed—If numerous enough that only thin walls separate individual pits or vugs, this term further describes the preceding nomenclature to indicate cell-like form.

- Vesicle (vesicular)—Small openings in volcanic rocks of variable shape formed by entrapped gas bubbles during solidification.

4. Color.—As a minimum, provide the color of wet altered and unaltered or fresh rock. Reporting color for both wet and dry material is recommended since materials may have significant color difference that may cause confusion. The Munsell Color System, specifically the Geologic Society of America Rock Color Chart, is to be used to provide standard color names and assist in cor-

relation. This also provides uniform and identifiable colors to others. Color symbols are optional unless necessary for clarity, i.e., light brown (5YR 5/6). Terms such as banded, streaked, mottled, speckled, and stained may be used to describe color further. Also describe colors of bands, etc.

Bedding, Foliation, and Flow Texture.—These features give the rock anisotropic properties or represent potential failure surfaces. Continuity and thickness of these features influence rock mass properties and cannot always be tested in the laboratory. Descriptors in table 4-3 are to be used to identify these thicknesses.

Table 4-3. – Bedding, foliation, or flow texture descriptors.

Descriptors	Thickness/spacing
Massive	Greater than 10 ft (3 m)
Very thickly, (bedded, foliated, or banded)	3 to 10 ft (1 to 3 m)
Thickly	1 to 3 ft (300 mm to 1 m)
Moderately	0.3 to 1 ft (100 to 300 mm)
Thinly	0.1 to 0.3 ft (30 to 100 mm)
Very thinly	0.03 [3/8 in] to 0.1 ft (10 to 30 mm)
Laminated (intensely foliated or banded)	Less than 0.03 ft [3/8 in] (<10 mm)

Weathering and Alteration.

1. Weathering.—Weathering, the chemical or mechanical degradation of rock, can significantly affect the engineering properties of the rock and rock mass. The term "weathering" for engineering geology descriptions in-

cludes both chemical disintegration (decomposition) and mechanical disaggregation as agents of alteration. Weathering effects generally decrease with depth, although zones of differential weathering can occur and may modify a simple layered sequence of weathering. Examples of these are: (1) differential weathering within a single rock unit, apparently due to relatively higher permeability along fractures; (2) differential weathering between different or the same rock units, usually due to compositional or textural differences; (3) differential weathering of contact zones associated with thermal effects such as interflow zones within volcanics; and (4) directional weathering along permeable joints, faults, shears, or contacts which act as conduits along which weathering agents penetrate more deeply into the rock mass.

Weathering does not correlate directly with specific geotechnical properties used for many rock mass classifications. However, weathering is important because it may be the primary criterion for determining depth of excavation, cut slope design, method and ease of excavation, and use of excavated materials. Porosity, absorption, compressibility, shear and compressive strengths, density, and resistance to erosion are the major engineering parameters influenced by weathering. Weathering generally is indicated visually by changes in the color and texture of the body of the rock, color, and condition of fracture fillings and surfaces, grain boundary conditions, and physical properties such as hardness.

Weathering is to be reported using descriptors presented in table 4-4 which divides weathering into categories that reflect definable physical changes due to chemical and mechanical processes. This table summarizes general descriptions which are intended to cover ranges in bedrock conditions. Most weathering tables generally are applicable to all rock types; however, they are easier to apply to crystalline rocks and those which contain ferromagnesian minerals. Weathering in many sedimentary rocks will not always conform to the criteria established in table 4-4, and weathering categories may have to be modified for particular site conditions. However, the basic horizontal categories and descriptors presented are to be used. Site-specific conditions such as fracture openness, filling, and degree and depth of penetration of oxidation from fracture surfaces should be identified and described.

2. Alteration.—Chemical alteration effects distinct from chemical and mechanical degradation (weathering), such as hydrothermal alteration, may not fit into the horizontal suite of weathering categories portrayed in table 4-4. Oxides may or may not be present. These types of alteration are site-specific, may be either deleterious or beneficial, and may affect some rock units and not others at a particular site. For those situations where the alteration does not relate well to the weathering categories, the geologist will need to adjust the description within the framework of table 4-4. Many of the general characteristics may not change, but the degree of discoloration and oxidation in the body of the rock and on fracture surfaces could be very different. Appropriate descriptors such as moderately altered or intensely altered may be assigned for each alteration category. If alteration is present, a description of products, depths of alteration, or mineral should be described.

3. Slaking.—Slaking is another type of disintegration which affects parameters used for design and construction. Terminology and descriptive criteria to identify this deleterious property are difficult to standardize because some materials air slake, many water slake, and some slake only after one or more wet-dry cycles. The Durability Index is a simplified method for describing slaking as representative of foundation excavation conditions. Criteria for the index are based on time exposed and effects noted in the field (see table 4-5). These simplified criteria do not specify whether the specimen or exposure is wetted, dried, or subjected to cyclic wetting and drying, and/or freeze-thaw. When reporting slaking or durability, a complete description includes the conditions to which the exposure was subjected. For example, the material could be classified as having "characteristics of DI3 upon drying." Slaking is not the same as the effects of bedding separation or disaggregation produced by stress relief.

Reclamation has not established a standard laboratory test for quantifying slaking durability. A field test suitable

Table 4-4. – Weathering descriptors.

Descriptors		Diagnostic features					General characteristics (strength, excavation, etc.)§
		Chemical weathering—Discoloration and/or oxidation		Mechanical weathering – Grain boundary conditions (disaggregation) primarily for granitics and some coarse-grained sediments	Texture and solutioning		
Alphanumeric descriptor	Descriptive term	Body of rock	Fracture surfaces†		Texture	Solutioning	
W1	Fresh	No discoloration, not oxidized	No discoloration or oxidation	No separation, intact (tight)	No change	No solutioning	Hammer rings when crystalline rocks are struck. Almost always rock excavation except for naturally weak or weakly cemented rocks such as siltstones or shales.
W2	Slightly weathered to fresh*						
W3	Slightly weathered	Discoloration or oxidation is limited to surface of, or short distance from, fratures; some feldspar crystals are dull	Minor to complete discoloration or oxidation of most surfaces	No visible separation, intact (tight)	Preserved	Minor leaching of some soluble minerals may be noted	Hammer rings when crystalline rocks are struck. Body of rock not weakened. With few exceptions, such as siltstones or shales, classified as rock excavation.
W4	Moderately to slightly weathered*						
W5	Moderately weathered	Discoloration or oxidation extends from fractures, usually throughout; Fe-Mg minerals are "rusty," feldspar crystals are "cloudy."	All fracture surfaces are discolored or oxidized	Partial separation of boundaries visible	Generally preserved	Soluble minerals may be mostly leached	Hammer does not ring when rock is struck. Body of rock is slightly weakened. Depending on fracturing, usually is rock excavation except in naturally weak rocks such as siltstones or shales.
W6	Intensely to moderately weathered*						
W7	Intensely weathered	Discoloration or oxidation throughout; all feldspars and Fe-Mg minerals are altered to clay to some extent; or chemical alteration produces in situ disaggregation, see grain boundary conditions	All fracture surfaces are discolored or oxidized, surfaces friable	Partial separation, rock is friable; in semiarid conditions granitics are disaggregated	Texture altered by chemical disintegration (hydration, argillation)	Leaching of soluble minerals may be complete	Dull sound when struck with hammer; usually can be broken with moderate to heavy manual pressure or by light hammer blow without reference to planes of weakness such as incipient or hairline fractures, or veinlets. Rock is significantly weakened. Usually common excavation.
W8	Very intensely weathered						
W9	Decomposed	Discolored or oxidized throughout, but resistant minerals such as quartz may be unaltered; all feldspars and Fe-Mg minerals are completely altered to clay		Complete separation of grain boundaries (disaggregated)	Resembles a soil, partial or complete remnant rock structure may be preserved; leaching of soluble minerals usually complete		Can be granulated by hand. Always common excavation. Resistant minerals such as quartz may be present as "stringers" or "dikes."

Note: This chart and its horizontal categories are more readily applied to rocks with feldspars and mafic minerals. Weathering in various sedimentary rocks, particularly limestones and poorly indurated sediments, will not always fit the categories established. This chart and weathering categories may have to be modified for particular site conditions or alteration such as hydrothermal effects; however, the basic framework and similar descriptors are to be used.

* Combination descriptors are permissible where equal distribution of both weathering characteristics are present over significant intervals or where characteristics present are "in between" the diagnostic feature. However, dual descriptors should not be used where significant, identifiable zones can be delineated. When given as a range, only two adjacent terms may be combined (i.e., decomposed to lightly weathered or moderately weathered to fresh) are not acceptable.

† Does not include directional weathering along shears or faults and their associated features. For example, a shear zone that carried weathering to great depths into a fresh rock mass would not require the rock mass to be classified as weathered.

§ These are generalizations and should not be used as diagnostic features for weathering or excavation classification. These characteristics vary to a large extent based on naturally weak materials or cementation and type of excavation.

Table 4-5. – Durability index descriptors.

Alphanumeric descriptor	Criteria
DI0	Rock specimen or exposure remains intact with no deleterious cracking after exposure longer than 1 year
DI1	Rock specimen or exposure develops hairline cracking on surfaces within 1 month, but no disaggregation within 1 year of exposure.
DI2	Rock specimen or exposure develops hairline cracking on surfaces within 1 week, and/or disaggregation within 1 month of exposure.
DI3	Specimen or exposure may develop hairline cracks in 1 day and displays pronounced separation of bedding and/or disaggregation within 1 week of exposure.
DI4	Specimen or exposure displays pronounced cracking and dissagregation within 1 day (24 hours) of exposure. Generally ravels and degrades to small fragments.

for evaluating the degree and rate of slaking for materials, primarily clayey materials and altered volcanics, is described below. The test is similar to that used by the Corps of Engineers. The slaking test evaluates the disaggregation of an intact specimen in water and reflects the fabric of the material, internal stresses, and character of the interparticle bonds.

To evaluate slaking behavior, immerse two intact specimens (pieces of core or rock fragments consisting of a few cubic inches) in water. One piece should be a natural water content (wrapped jar sample) and one piece from an air-dried sample. Test results should be photographed with labels to identify specimens and exposure times.

Results of both specimens should be reported. Describe the behavior of the specimens as follows:

a. Volume changes.—The volume of the material reduced to individual particles should be estimated and compared to the initial volume of material. The degree of disaggregation is described using the following descriptive criteria:

None	No discernable disaggregation
Slight	Less than 5 percent of the volume disaggregated
Moderate	Between 5 and 25 percent of the volume disaggregated
Intense	More than 25 percent but less than the total volume disaggregated
Complete	No intact piece of the material remains (complete disaggregation)

b. Rate of slaking.—The following descriptors are used to identify the time to slake:

Slow slaking	Action continues for several hours
Moderate slaking	Action completed within 1 hour
Rapid slaking	Action completed within 2 minutes
Sudden slaking	Complete reaction, action completed instantaneously

[Slaking is generally used for shales; disaggregation is used mostly for soils.]

4. Character of material.—The character of the remaining pieces of material after the test is completed are described as follows:

No change	Material remains intact
Plates remain	Remaining material present as platy fragments of generally uniform thickness
Flakes remain	Remaining material present as flaky or wedge-shaped fragments
Blocks remain	Blocky fragments remain
Grains remain	Remaining material chiefly present as sand-size grains
No fragments	Remaining material entirely disaggregated to clay-size particles

Hardness—Strength.—Hardness can be related to rock strength as a qualitative indication of density and/or resistance to breaking or crushing. Strength is a necessary engineering parameter for design that frequently is not assessed, but it plays a dominant role in engineering design and construction, such as tunnel support requirements, bit wear for drilling or TBM (tunnel boring machines) operations, allowable bearing pressures, excavation methods and support. All of these often depend on the rock strength. The large differences in hardness are the most important, not the subtle differences.

The hardness and strength of intact rock and the rock mass are functions of the individual rock type but may be modified by weathering or alteration. Hardness and strength are to be described for each geologic unit when they are functions of the rock type and also for zones of alteration or weathering when there are various degrees of hardness and/or strength due to different degrees of weathering or chemical alteration. When evaluating strengths, it is important to note whether the core or rock fragments break around, along, or through grains; or along or across incipient fracture, bedding, or foliation.

Hardness and especially strength are difficult characteristics to express with field tests. Two field tests can be used; one is a measure of the ability to scratch the surface of a specimen with a knife, and the second is the resistance to fracturing by a hammer blow. Results from both tests should be reported. The diameter and length of core or the size of fragment will influence the geologist's estimation of strength, and this should be kept in mind when correlating strengths. A 5- to 8-inch (130- to 200-mm) length of N-size core or rock fragment, if available, should be used for hardness determinations to preclude erroneously reporting local rather than average hardness, and to evaluate the tendency to break along incipient fractures and textural or structural features when struck with a geologic hammer. To maintain consistency, each geologist should calibrate his/her standards (heavy, moderate, and light hammer blow) with those of other geologists mapping or logging core for a particular project.

Descriptors used for rock hardness/strength are shown on table 4-6.

A few empirical and quantitative field techniques which are quick, easy, and inexpensive are available to provide estimates of strengths.

Quantitative estimates of strengths can be obtained from the point load test. A lightweight and portable testing device is used to break a piece of core (with a minimum length at least 1.5 times the diameter) between two loading points. If a new fracture does not run from one loading point to the other upon completion of the test, or if the points sink into the rock surface causing excessive deformation or crushing, the test should not be recorded. Raw data are to be given with the reduced data (equations to empirically convert load data to compressive strengths are usually supplied with the equipment). The Schmidt (*L*) hammer may also be used for estimating rock strengths; refer to Field Index Tests in chapter 5. Both of these tests can be used to calibrate the manual index (empirical) properties described the table 4-6, and a range of compressive strengths can be assigned. Depending on the scope of the study and structure being considered, laboratory testing may be required or could be used to confirm the field test data.

Discontinuities.—Describe all discontinuities such as joints, fractures, shear/faults, and shear/fault zones, and significant contacts. These descriptions should include all observable characteristics such as orientation, spacing, continuity, openness, surface conditions, and fillings. Appropriate ter-

Table 4-6. – Rock hardness/strength descriptors.

Alphanumeric descriptor	Descriptor	Criteria
H1	Extremely hard	Core, fragment, or exposure cannot be scratched with knife or sharp pick; can only be chipped with repeated heavy hammer blows.
H2	Very hard	Cannot be scratched with knife or sharp pick. Core or fragment breaks with repeated heavy hammer blows.
H3	Hard	Can be scratched with knife or sharp pick with difficulty (heavy pressure). Heavy hammer blow required to break specimen.
H4	Moderately hard	Can be scratched with knife or sharp pick with light or moderate pressure. Core or fragment breaks with moderate hammer blow.
H5	Moderately soft	Can be groovved 1/16 inch (2 mm) deep by knife or sharp pick with moderate or heavy pressure. Core or fragment breaks with light hammer blow or heavy manual pressure.
H6	Soft	Can be grooved or gouged easily by knife or sharp pick with light pressure, can be scratched with fingernail. Breaks with light to moderate manual pressure.
H7	Very soft	Can be readily indented, grooved or gouged with fingernail, or carved with a knife. Breaks with light manual pressure.

Any bedrock unit softer than H7, very soft, is to be described using USBR 5000 consistency descriptors.

Note: Although "sharp pick" is included in these definitions, descriptions of ability to be scratched, grooved or gouged by a knife is the preferred criteria.

minology, descriptive criteria and descriptors, and examples pertaining to discontinuities are presented in Chapter 5.

Contacts.—Contacts between various rock units or rock/soil units must be described. In addition to a geologic classification, describe their engineering characteristics such as their planarity or irregularity and other descriptors used for discontinuities.

Descriptors applicable to the geologic classification of contacts are:

- Conformable
- Unconformable
- Welded—contact between two lithologic units, one of which is igneous, that has not been disrupted tectonically
- Concordant (intrusive rocks)
- Discordant (intrusive rocks)

Descriptors pertinent to engineering classification of contacts are:

- Jointed—contact not welded, cemented, or healed—a fracture
- Intact

- Healed (by secondary process)
- Sharp
- Gradational
- Sheared
- Altered (baked or mineralized)
- Solutioned

If jointed or sheared, additional discontinuity descriptors such as thickness of fillings, openness, moisture, roughness, should be provided also (see discontinuity descriptors).

Permeability Data.—Permeability (hydraulic conductivity) is an important physical characteristic that must be described. Suggested methods for testing, terminology, and descriptors are available in the *Earth Manual* and *Ground Water Manual*. Numerical values for *k* (hydraulic conductivity) can be determined using any of several methods including ERC computer programs. These values may be shown on drill hole logs. For narrative discussions or summary descriptions, the numerical value and descriptors may be used. Descriptors to be used—such as low, moderate—are those shown on figure 4-6 which complements figure 2-5 in the *Ground Water Manual*.

Example Descriptions

The examples which follow are presented as representative formats for describing bedrock in the physical conditions column of drill hole logs and on a General Legend, Explanation, and Notes drawing.

Core Log Narrative

Several examples of descriptions for core logs are presented. These examples illustrate format and the use of the lithologic descriptors but do not include a description of discontinuities.

Log with Alphanumeric Descriptors and English Units.

... 12.6 to 103.6: Amphibolite Schist (JKam). Fine grained (0.5 to 1 mm); subschistose to massive; greenish-black (5G 2/1) with numerous blebs and stringers of white calcite to 0.02 ft thick with solution pits and vugs

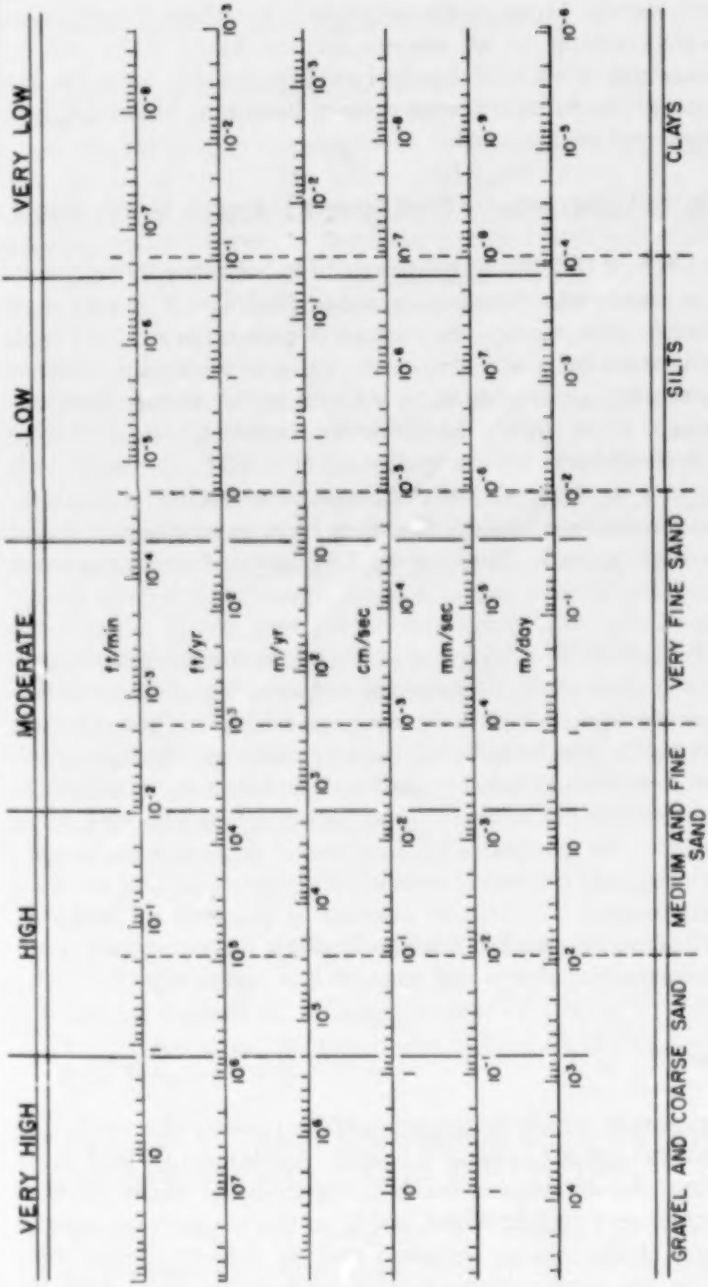


Figure 4-6.—Permeability conversion chart.

to 0.03 ft, mostly 0.01 ft, aligned subparallel to foliation; very thinly foliated, foliation dips 65° to 85°, steepening with depth. Moderately to slightly weathered (w4), iron oxide staining on all discontinuities. Hard (H3), can be scratched with knife with heavy pressure, core breaks parallel to foliation with heavy hammer blow. Slightly fractured (FD3), ...

Log with Alphanumeric Descriptors Using SI Metric Units.

103.60 to 183.22: Sandstone (TU_{sA}). Ferruginous quartzose sandstone. Medium grained (0.25 to 0.5 mm), well sorted, subrounded to rounded quartz grains are well cemented by silica, hematite occurs as minor cement agent and as thin coating on grains. Moderate reddish-brown (10R 6/6). Moderately bedded, beds 250 to 310 mm thick, bedding dips 15° to 29°, averages 18°. Slightly weathered. Hard, cannot be scratched with knife, core breaks with heavy hammer blow across bedding and through grains. Moderately fractured. Core recovered . . . .

172.41-176.30: Claystone (TU_{c2}). Calcareous montmorillonitic clay with 20 percent subangular, fine sand-size quartz fragments. Strong reaction with HCl, grayish pink (5R 8/2). Moderately to rapidly slaking when dropped in water. Very thinly bedded to laminated with bed thickness from 8 to 20 mm. Very intensely weathered. Very soft, can be gouged with fingernail, friable, core breaks with manual pressure, smaller fragments can be crushed with fingers . . . Upper contact is parallel to bedding, conformable, gradational, and intact; lower contact is unconformable, sharp and jointed but tight; dips 35° . . . .

Legend

The example which follows could be typical of a rock unit description on a General Legend, Explanation, and Note Drawing. An attempt is made to describe as many physical properties as possible which apply to the entire rock unit at the site. If individual subunits can be differentiated, they could be assigned corresponding symbols and described below the undifferentiated description. Those characteristics in the subunits which are similar or are included in the undifferentiated unit do not need to be repeated for each subunit.

Amphibolite schist-undifferentiated.—Mineralogy variable but generally consists of greater than 30 percent amphibole. Contains varying percentages of feldspar, quartz, and epidote in numerous, thin, white and light green (5G 7/4), discontinuous stringers and blebs. Texture ranges from fine grained and schistose to medium grained and subschistose. Overall, color ranges from greenish black (5G 2/1) to olive black (5Y 2/1). Thinly foliated; foliation dips steeply 75° to 85° NE. Weathering is variable but generally moderately weathered to depths of 75 ft, slightly weathered to 120 ft, and fresh below. Where oxidized, moderate reddish-brown (10R 4/6), frequently with dendritic patterns of oxides on discontinuities. Hard, fresh rock can be scratched slightly with heavy knife pressure; fresh N-size core breaks along foliation with moderate to heavy hammer blow. Foliation joints are variably spaced and discontinuous, spaced more closely where weathered. Joint sets are prominent but discontinuous. (Joint sets are identified in the specifications paragraphs). Commonly altered 0.1 to 6 ft along contacts of dikes and larger shears with epidote and quartz ("altered amphibolite" on logs of exploration). When altered, harder than amphibolite. Based on drill hole permeability testing, hydraulic conductivity is very low to low, with values ranging from 0.09 to 130 ft/yr averages 1.5 ft/yr in slightly weathered and fresh rock.

BIBLIOGRAPHY

[1] Travis, Russell B., "Classification of Rocks," v 50, No. 1, Quarterly of the Colorado School of Mines, Golden, CO, January 1955.

[2] Fisher, R. V., "Rocks Composed of Volcanic Fragments: *Earth Science Review*, v. I, pp. 287-298, 1966.

[3] Williams, H., and McBirnig, A., *Volcanology*, published by Freeman, Cooper and Company, San Francisco, CA. 391 pp., 1979.

[4] Compton, Robert R., *Manual of Field Geology*, published by John Wiley & Sons, Inc., New York, NY, 1962.

Chapter 5

TERMINOLOGY AND DESCRIPTIONS FOR DISCONTINUITIES

General

Structural breaks strongly influence the mechanical behavior of geologic materials. In most rock masses, they form planes of weakness or surfaces of separation which include foliation and bedding joints, joints, fractures, and zones of crushing or shearing. These discontinuities, to a large extent, control the strength, deformation, and permeability of geologic materials and their use in construction. Many engineering problems relate to discontinuities rather than to rock type or strength. Therefore, discontinuities must be carefully and adequately described. This chapter establishes terminology, indexes, qualitative and quantitative descriptive criteria, and format for describing discontinuities. Much of the descriptive criteria contained in this chapter is similar to other established sources which are accepted as international standards (for example, ISRM, 1978 [1]). Indexes, descriptors, and their associated criteria presented in this section may be modified, but only if clearly justified and documented.

Discontinuity Terminology

The use of quantitative and qualitative descriptors requires that what is being described is clearly identified. Nomenclature associated with structural breaks in geologic materials is frequently misunderstood. For example, bedding, bedding planes, bedding plane partings, bedding separations, and bedding joints may have been used to identify similar or distinctly different geological features to different Reclamation geologists. Therefore, the terminology for discontinuities which is presented in this chapter should be used uniformly for all Reclamation geology programs. Additional definitions for various types of discontinuities are presented in the *Glossary of Geology;* these may be used to describe further structural breaks. However, the following basic definitions should not be modified unless clearly justified and, if so, they must be defined thoroughly.

Discontinuity.—A collective term used for all structural breaks in geologic materials which usually have zero to low tensile strength. Discontinuities also may be healed. Discontinuities comprise fractures (including joints), planes of weakness, shears/faults, and shear/fault zones. Also, depositional or erosional contacts between various geologic units often may be considered discontinuities. For discussion of contacts, refer to chapter 4.

Fracture.—A term used to describe any natural break in geologic material excluding shears and shear zones. Examples of the most prevalent fractures are shown in figure 5-1 and are defined as follows:

1. Joint.—A fracture which is relatively planar along which there has been little or no obvious displacement parallel to the plane. In many cases, a slight amount of separation normal to the joint surface has occurred. A series of joints with similar orientation form a joint set. Joints may be open, healed, or filled, and surfaces may be striated due to minor movement. Fractures which are parallel to bedding are termed bedding joints or bedding plane joints. Those fractures parallel to metamorphic foliation are called foliation joints.

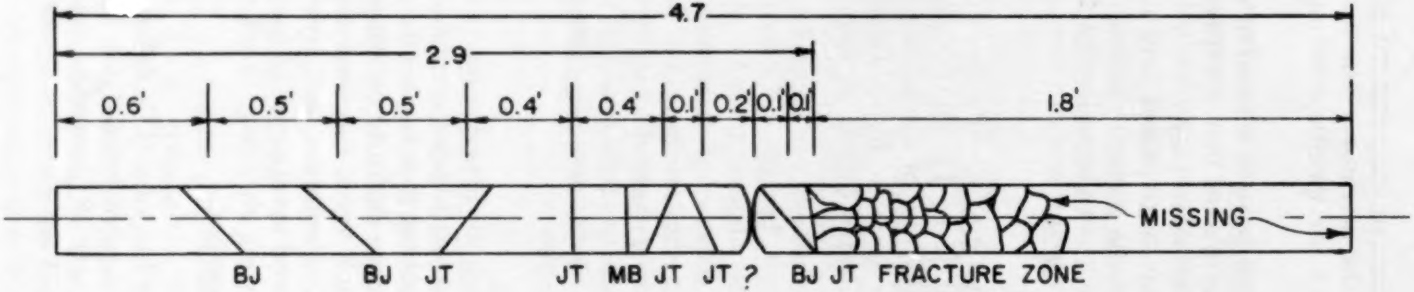
2. Bedding plane separation.—A separation along bedding planes after exposure due to stress relief or slaking.

3. Random fracture.—A fracture which does not belong to a joint set with rough, highly irregular, and nonplanar surfaces along which there has been no obvious shear displacement.

4. Shear.—A structural break where differential movement has occurred along a surface or zone of failure by shear; characterized by polished surfaces, striations, slickensides, gouge, breccia, mylonite, or any combination of these. Often direction, amount of displacement, and continuity may not be known because of limited exposures or observations.

5. Fault.—A shear with significant continuity which can be correlated between observation locations; occurs across a significant portion of a given site, foundation

1. PERCENTAGE OF SOLID CORE SEGMENTS LONGER THAN 0.33 ft (100mm) RELATIVE TO CORE RUN LENGTH, EXCLUDING MECHANICAL BREAKS.
2. RECORDED AS CALCULATED PERCENTAGE FOR EACH RUN.
3. BEST FOR N-SIZE OR LARGER SIZE CORE.
4. MAY NOT BE APPLICABLE FOR VERY LOW STRENGTH, FISSILE OR FOLIATED ROCKS WHICH BREAK OR PART EASILY.



$$\mathrm{RQD} = \frac{\text{Sum of length of pieces} \geq 0.33\text{ ft (4in)}}{\text{(total length of core run)}} \times 100 = \frac{2.4}{4.7} \times 100 = 51\,\%$$

Figure 5-1.—Rock quality designation (RQD) computation.

area, or region; or is a segment of a fault or fault zone reported in the literature. The designation of a fault or fault zone is a site-specific determination.

6. Shear/fault zone.—A band of parallel or subparallel fault or shear planes that is expressed in relative terms of width. The zone may consist of gouge, breccia, or many fault or shear planes with fractured and crushed rock between the shears or faults, or any combination of these. In the literature, many fault zones are simply referred to as faults.

7. Shear/fault gouge.—Pulverized (silty, clayey, or clay-size) material derived from crushing or grinding of rock caused by shearing, or the subsequent decomposition or alteration by geologic fluids. Gouge may be soft, uncemented, indurated (hard), or mineralized.

8. Shear/fault breccia.—Cemented or uncemented, predominantly angular (may be platy, rounded, or contorted) and commonly slickensided rock fragments resulting from the crushing or shattering of geologic materials during shear displacement. Breccia may range from sand-size to large boulder-size fragments, usually within a matrix of fault gouge. Breccia may consist solely of mineral grains.

9. Shear/fault-disturbed zone.—An associated zone of fractures and/or folds adjacent to a shear or shear zone where the country rock has been subjected to only minor cataclastic action and may be mineralized. If adjacent to a fault or fault zone, the term is fault-disturbed zone. Occurrence, orientation, and areal extent of these phenomena depend upon depth of burial (pressure and temperature) during shearing, brittleness of materials, and the stress envelope.

Terminology for joint (JT), foliation joint (FJ), bedding joint (BJ), incipient joint (IJ) or incipient fracture (IF), random fracture (RF), mechanical break (MB) and fracture zone (FZ) are given on figure 5-9 (drawing no. 40-D-6499).

Indexes for Describing Fracturing

Fracture Density

Fracture density is based on the spacing between all natural fractures in an exposure or core recovery lengths in drillholes, excluding mechanical breaks, shears, and shear zones; however, shear-disturbed zones (fracturing outside the shear) are included. In this context, fracture is a general term and includes all natural breaks such as joints, bedding joints, foliation joints, and random fractures. Fracture density always should be described in physical measurements, but summary descriptive terms relating to these measurements are a convenient aid in communicating characteristics of the rock mass. Standard descriptors apply to all rock exposures, such as tunnel walls, dozer trenches, outcrops, or foundation cut slopes and inverts, as well as boreholes. Descriptors presented in table 5-1 and figure 5-9 are based on drill hole cores where lengths are measured along the core axis.

When describing fracture density, provide a percentage of the types of fractures. A complete description for fracture density might read: Slightly Fractured (FD3), recovered core in 0.8- to 4.7-feet (0.2- to 1.4-m) lengths, mostly 1.7 feet (520 mm) 25% bedding joints/ 75% joints.

Fracture Frequency

Fracture frequency is the number of fractures occurring within a base length of core run. The number of natural fractures is divided by the length and is reported as fractures per foot or fractures per meter.

RQD (Rock Quality Designation)

RQD (after Deere [2]) is a fracture index used in many rock classification systems. To determine the RQD value, sum the total lengths of solid core which are 4 inches (100 mm) or more in length (i.e., two times the diameter of the core). If the core is broken by handling or the drilling process (mechanical breaks), the broken pieces are fitted together and counted as one piece provided that they form the req-

Table 5-1. – Fracture density descriptors.

Alpha-numeric descriptor	Descriptor	Criteria (excludes mechanical breaks)
FD0	Unfractured	No observed fractures.
FD1	Very slightly fractured	Core recovered mostly in lengths greater than 3 feet (1 m).
FD2	Slightly to very slightly fractured*	
FD3	Slightly fractured	Core recovered mostly in lengths from 1 to 3 feet (300 to 1000 mm) with few scattered lengths less than 1 foot (300 mm) or greater than 3 feet (1000 mm).
FD4	Moderately to slightly fractured*	
FD5	Moderately fractured	Core recovered mostly in lengths from 0.33 to 1.0 foot (100 to 300 mm) lengths with most lengths about 0.67 foot (200 mm).
FD6	Intensely to moderately fractured*	

Table 5-1. – Fracture density descriptors.—Continued

Alpha-numeric descriptor	Descriptor	Criteria (excludes mechanical breaks)
FD7	Intensely fractured	Lengths average from 0.1 to 0.33 foot (30 to 100 mm) with scattered fragmented intervals. Core recovered mostly in lengths less than 0.33 foot (100 mm).
FD8	Very intensely to intensely fractured*	
FD9	Very intensely fractured	Core recovered mostly as chips and fragments with a few scattered short core lengths

* Combinations of fracture densities are permissible (e.g., very intensely to intensely fractured or moderately to slightly fractured) where equal distribution of both fracture density characteristics are present over a significant core interval or exposure, or where characteristics are "in between" the descriptor definitions.

uisite length of 4 inches (100 mm). The length of these pieces are measured along the centerline of the core. This sum is divided by the length of the run (drill interval) and recorded on the log as a percentage of each run. Figure 5-1 is an example of RQD measurements and procedures.

RQD estimates can be determined from outcrops when drill hole data either are not available or needs to be supplemented. Barton et. al. [3] has shown that RQD = 115 - 3.3 *Jv*, where *Jv* equals the total number of joints in a cubic meter. RQD may also be estimated from an outcrop by the following method: determine the sum of solid rock (fracture free) in lengths 4 inches long or greater along a line that simulates either a 5- or 10-foot "core run". Several orientations of the line are needed in this method to overcome bias in selecting an orientation and in obtaining an average RQD value. Both of these methods offer an advantage over RQD's determined from a drill hole because they include all fracture orientations. Also, these RQD values more realistically represent rock conditions in (future) rock cuts and tunnels.

Description of Fractures

An accurate description of fractures is as important if not more so, than the physical characteristics of the rock or soil. Fractures affect and usually control the strength, deformation, and permeability characteristics of a rock mass. Fractures are to be categorized into sets based on similar orientations, and each set is to be labeled and described. Along with the physical measurements, such as attitude, spacing, and continuity, include information such as: composition, thickness and hardness of fillings or coatings; characteristics of surfaces, such as hardness, roughness, waviness and alteration; healing; fracture openness; and presence of possible waterflow. The determination of joint and fracture properties also may be useful for correlating purposes. The cleavage (CL) in metamorphic rocks includes slaty cleavage, Crenulation cleavage, phyllitic structure, and schistosity (after Davis [3]) and often can be used to evaluate the tectonic setting.

Figure 5-9, standard drawing 40-D-6499, may be used for geologic reports or specifications where the standard descriptors and terminology established for discontinuities are used during data collection. Suitable reproducibles (vellum or mylar) are available upon request.

Format for the Description of Fractures

Identifying and recording the physical characteristics of fractures during mapping and logging is the least expensive part of most geologic investigations. An accurate and concise description of these characteristics permits interpretation in geologic terms which is directly applicable to design and construction. As many of the characteristics should be described as possible, limited only by the type of observation. For example, continuity and waviness cannot be provided for joints observed in core. Examples of fracture descriptions recorded for a drill hole log and for an outcrop or exposure are in a following section. A general format for recording fracture descriptions follows:

- Orientation
- Spacing
- Continuity
- Openness
- Fillings
  - Thickness
  - Composition
  - Weathering/alteration
  - Hardness
- Healing
- Surfaces
  - Roughness
  - Waviness
  - Weathering/alteration
  - Hardness
- Field index text - if performed
- Moisture

Descriptors for Fracture Characteristics

The following paragraphs present terminology, descriptor criteria, and descriptors for recording fracture data. Alphanumeric descriptors provided are compatible with the computer generated "rock properties" logs (NGEOSUB).

Alphanumeric descriptors are not a substitute for a complete description of the fracture characteristics.

Orientation.—The orientation of all fractures with respect to applied loads can be critical to deformation or stability. Seepage or grouting also may be affected or controlled by orientation. Orientation is to be measured in the field and the raw data tabulated and interpreted. The analysis and interpretation are to include stereonet contour diagrams, identification of sets and subsets, and their areal distribution. Depending on map scales, actual joint traces, representative strikes and dips, and/or miniature stereonet diagrams, joint set diagrams, or apparent dip blocks are to be shown on appropriate geologic drawings (see fig 7-4, *Engineering Geology Office Manual*). Azimuths or quadrants may be used. The method of measuring the dip of planar discontinuities, foliation, and bedding in cores in shown on figure 5-9.

On figure 5-9, the insert figures A and B demonstrate how inclination of a joint in core from an angle hole can be interpreted as a horizontal joint (A) or vertical joint (B) by merely rotating the core 180°. Where core is oriented, and the top of core is known, the inclination can be recorded as positive (+) or negative (−) to avoid ambiguity and to assist in determining sets.

Fracture orientation is recorded as strike and dip, or as azimuth and dip in exposure. Orientation of planar features with undetermined strike can be measured directly and reported as dip in vertical holes. In angle holes, where true dip is not known, the angle of the plane should be measured from the core axis and reported as inclination, i.e., "bedding plane joints inclined 65 degrees from the core axis."

Spacing.—Spacing affects block size and geometry in the rock mass. Spacing is, therefore, a required input to several rock mass classification systems. When a set can be distinguished (parallel or subparallel joints), true spacing can be measured and is described for each joint set, as shown on figure 5-2 and in table 5-2. If apparent spacing is given, it must be so stated.

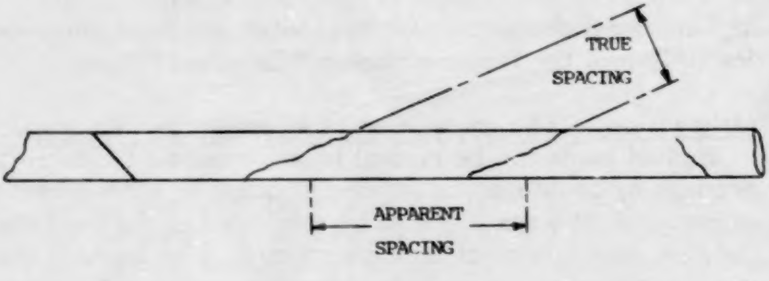


Figure 5-2.—Comparison of true and apparent spacing.

Continuity.—A continuous joint or fracture is weaker and more deformable than a short discontinuous set bridged by intact bedrock. Recording trace lengths to describe continuity is useful in large exposures Identification of the more continuous fractures is the most important aspect of formulating rock stability input data, especially for high cut slopes and in large underground openings. Record the longest observable trace regardless of ends and note whether it is a strike (S), dip (D), or apparent (A) trace. Descriptors for continuity are provided in table 5-3.

However, this information alone is not sufficient to completely assess joint or fracture continuity because observable trace lengths may be partially obscured. Therefore, when performing joint studies or surveys, it is important to record the number of ends (fracture terminations) that can be seen in exposure using the alphanumeric descriptors shown in table 5-4. The size of the exposure should be noted because this is a determining factor when surveying for visible ends.

Openness.—The width or aperture is measured normal to the fracture surface. This aperture or openness affects the

Table 5-2. – Fracture spacing descriptors.

Alphanumeric descriptor	Joint or fracture spacing descriptor	True spacing
SP1	Extremely widely spaced	Greater than 10 ft (>3 m)
SP2	Very widely spaced	3 to 10 ft (1 to 3 m)
SP3	Widely spaced	1 to 3 ft (300 mm to 1 m)
SP4	Moderately spaced	0.3 to 1 ft (100 to 300 mm)
SP5	Closely spaced	0.1 to 0.3 ft (30 to 100 mm)
SP6	Very closely spaced	Less than 0.1 ft (<30 mm)

strength, deformability, and seepage characteristics. Describe fracture openness by the categories shown in table 5-5. For drill logs, if actual openness cannot be measured or estimated, use only open or tight and do not assign an alphanumeric descriptor.

Table 5-3. – Fracture continuity descriptors.

Alphanumeric descriptor	Descriptor	Lenghts
C1	Discontinuous	Less than 3 ft (>1 m)
C2	Slightly continuous	3 to 10 ft (1 to 3 m)
C3	Moderately continuous	10 to 30 ft (3 to 10 m)
C4	Highly continuous	30 to 100 ft (10 to 30 m)
C5	Very continuous	Greater than 100 ft (>30 m)

Table 5-4. – Descriptors for recording fracture ends in joint surveys.

Alphanumeric descriptor	Criteria
E0	Zero ends leave the exposure (both ends of the fracture can be seen in the exposure).
E1	One end can be seen (one end of the fracture terminates in the exposure).
E2	Both ends cannot be observed (two fracture ends do not terminate in the exposure).

Table 5-5. – Fracture openness descriptors.

Alpha-numeric descriptor	Descriptor	Openness
O0	Tight	No visible separation
O1	Slightly open	Less than 0.003 ft [1/32 in] (<1 mm)
O2	Moderately open	0.003 to 0.01 ft [1/32in to 1/8 in] (1 to 3 mm)
O3	Open	0.01 to 0.03 ft [1/8 to 3/8 in] (3 to 10 mm)
O4	Moderately wide	0.03 ft [3/8 in] to 0.1 ft (10 to 30 mm)
O5	Wide	Greater than 0.1 ft (>30 mm) (record actual openness)

Characteristics of Fracture Fillings.—Describing the presence or absence of coatings or fillings and distinguishing between types, alteration, weathering, and strength and hardness of the filling material may be as significant as fracture spatial relationships or planarity. Strength and permeability of fractures may be affected by fillings. Descriptions of fracture coatings and fillings are site-specific but must address the following considerations:

1. Thickness of Fillings.—Table 5-6 provides descriptors for recording the thickness of fracture fillings or coatings.

2. Composition of Fillings.—The mineralogical classification of fillings, such as quartz, gypsum, and carbonates, must be identified to convey physical properties of fractures that may be significant criteria for design. Soil materials in open fractures are to be described and classified according to the Unified Soil Classification system (see USBR 5000 and USBR 5005).

Fractures may be filled or "healed" entirely or over a significant portion of their areal extent by quartz, calcite, or other minerals. Veins may be present without healing the

Table 5-6. – Fracture filling thickness descriptors.

Alpha-numeric descriptor	Descriptor	Thickness
T0	Clean	No film or coating
T1	Very thin	Less than 0.003 ft [1/32 in] (<1 mm)
T2	Moderately thin	0.003 to 0.01 ft [1/32 to 1/8 in] (1 to 3 mm)
T3	Thin	0.01 to 0.03 ft [1/8 to 3/8 in] (3 to 10 mm)
T4	Moderately thick	0.03 ft [3/8 in] to 0.1 ft (10 to 30 mm)
T5	Thick	Greater than 0.1 ft (>30 mm) (record actual thickness)

fracture or may have been broken again forming new surfaces. Soluble fillings such as gypsum may cause foundation or structural degradation during the facility's expected lifetime. These considerations must not be overlooked during design, construction investigations, and monitoring, or potential long term stability, deformability, and seepage problems may require expensive rehabilitation efforts.

Coatings or fillings of chlorite, talc, graphite, or other low-strength materials also must be identified because of their deleterious effects on strength, especially when wet. Some fillings such as dispersive, erosive, or micaceous materials can squeeze, pipe under fluid flow, and contribute to a loss of strength and stability. Montmorillonitic clays may swell or cause swelling pressures. Cohesionless materials such as sands and silts or materials which have been crushed or altered may run or flow into underground excavations, or serve as seepage conduits.

3. Weathering or Alteration.—Descriptors for weathering or alteration of fracture fillings (excluding soil materials) are to be the same as those used for rock weathering.

4. Hardness/Strength.—Descriptors for hardness/strength of fillings should be the same as those presented for bedrock hardness or soil consistency (Chapters 3 and 4). Various field index tests may also be performed to determine strengths of fillings. Refer to the Field Index Tests in Chapter 4.

5. Healing.—Fractures may be healed or recemented by one or more episodes of subsurface mineralization or precipitation of soluble materials. A description of fracture healing or rehealing must include not only the type of healing or cementing agent, but an estimate of the degree to which the fracture has been healed. The subjective criteria and descriptors shown in table 5-7 are to be used to describe healing.

Characteristics of Fracture Surfaces.—The physical characteristics of fracture surfaces are very important for required deformability and stability analyses. Dimensional characteristics such as roughness and waviness (see fig. 5-3) and characteristics such as weathering and hardness of the surfaces are important in evaluating the shear strength of fractures. Fracture roughness descriptors are given in table 5-8. Surface characteristics are of less importance only when low-strength materials comprise fracture fillings.

The description of fracture asperities is divided into two categories: small-scale asperities or roughness and large-scale undulations or waviness. Figure 5-3 shows examples of these asperities. Descriptors for roughness and waviness and additional items related to fracture surfaces follow.

1. Roughness.—The roughness (small-scale asperities) of fracture surfaces is critical for evaluating shear strengths. Roughness descriptors such as striated or slickensided should be used whenever observed. For oriented core or outcrops, the orientation of striations or slickensides should be recorded. The rake of striations or slickensides should be recorded when observed in core from vertical drill holes which have not been oriented. In Coulomb's equation for shear strength ($S = C + N \tan \varphi$), the large scale undulations (i) are entered into the equation as $N \tan (\varphi + i)$.

Table 5-7. – Fracture healing descriptors.

Alpha-numeric descriptor	Descriptor	Criteria
HL0	Totally healed	Fracture is completely healed or recemented to a degree at least as hard as surrounding rock.
HL2	Moderately healed	Greater than 50 percent of fractured material, fracture surfaces, or filling is healed or recemented; and/or strength of the healing agent is less hard than surrounding rock.
HL3	Partly healed	Less than 50 percent of fractured material, filling, or fracture surface is healed or recemented.
HL5	Not healed	Fracture surface, fracture zone, or filling is not healed or recemented; rock fragments or filling (if present) held in place by their own angularity and/or cohesiveness.

2. Waviness.—Waviness (large-scale undulations) also should be recorded for fracture surveys along exposures. This may be accomplished by recording amplitude and wavelength, or as a minimum, describe as either planar or undulating.

3. Weathering/Alteration.—Weathering or alteration of fracture surfaces is one of the criteria used for classifying

Table 5-8. – Fracture roughness descriptors.

Alpha-numeric descriptor	Descriptor	Criteria
R1	Stepped	Near-normal steps and ridges occur on the fracture surface.
R2	Rough	Large, angular asperities can be seen.
R3	Moderately rough	Asperities are clearly visible and fracture surface feels abrasive.
R4	Slightly rough	Small asperities on the fracture surface are visible and can be felt.
R5	Smooth	No asperities, smooth to the touch.
R6	Polished	Extremely smooth and shiny.

rock mass weathering. Even though it is inherent in the weathering categories, the actual description of surface alteration and the associated loss of strength of the rock are to be reported. Qualitative information can be presented when describing a particular joint set, joint, or fracture. The condition of the surface(s) such as depth of penetration and degree of staining or oxidation is to be recorded.

Moisture conditions.—The presence of moisture or potential for waterflow along fractures may be an indicator of potential grout takes or seepage paths. Criteria and descriptors shown in table 5-9 are to be used to describe moisture conditions for fractures. The presence or absence of moisture cannot be determined in core, but evidence of previous long term waterflow is found in leaching, color changes, evidence of oxidation, and dissolutioning.

Field Index Tests

Schmidt (*L*) hammer tests can be used to estimate the hardness/strength of the rock surfaces along the discontinuity (which may be weaker than the body of the rock). The rebound of a spring-actuated projective is measured from the surface being tested. The sample should be large enough, preferably intact or securely fastened to a stable base (i.e., concrete), that it does not move during the tests. Unclamped specimens should measure at least 0.7 foot (200 mm) in each direction. Direct testing on rock outcrops is usually the best method. Results should be obtained from both wet and dry surfaces. Ten readings are taken at various locations on each

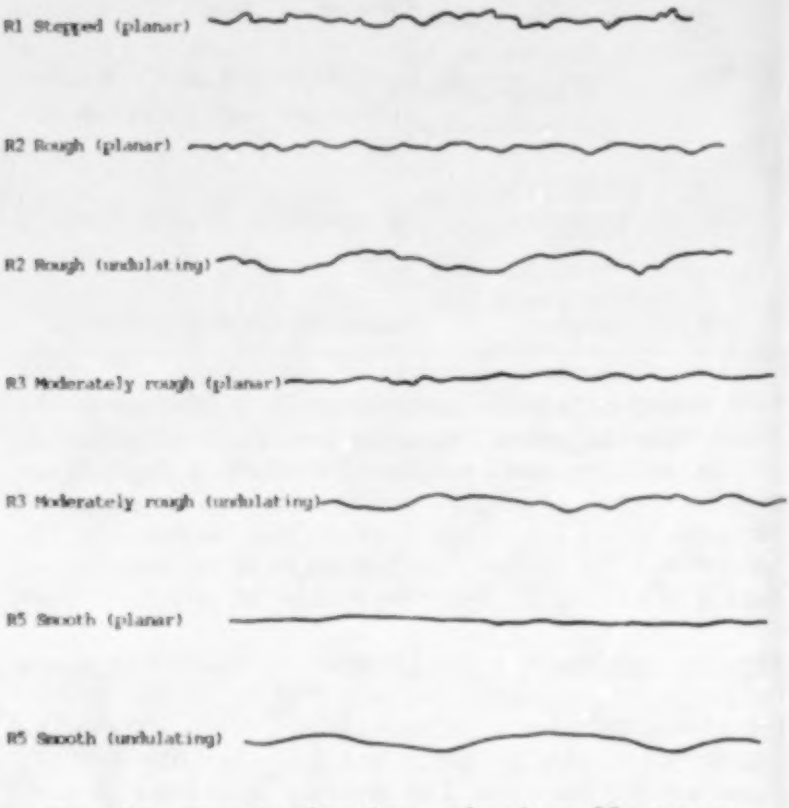


Figure 5-3.—Examples of roughness and waviness of fracture surfaces, typical roughness profiles, and terminology. The length of each profile is in the range of 3 to 15 feet (1 to 5 m); the vertical and horizontal scales are equal.

Table 5-9. – Fracture moisture conditions descriptors.

Alphanumeric descriptor	Criteria
M1	The fracture is dry. It is tight or filling (where present) is of sufficient density or composition to impede waterflow. Waterflow along the fracture does not appear possible.
M2	The fracture is dry with no evidence of previous waterflow. Water flow appears possible.
M3	The fracture is dry but shows evidence of waterflow such as staining, leaching, and vegetation.
M4	The fracture filling (where present) is damp, but no free water is present.
M5	The fracture shows seepage. It is wet with occasional drops of water.
M6	The fracture emits a continuous flow (estimate flow rate) under low pressure. Filling materials (where present) may show signs of leaching or piping.
M7	The fracture emits a continuous flow (estimate flow rate) under moderate to high pressure. Water is squirting and/or filling material (where present) may be substantially washed out.

surface. The five lowest readings are discounted and the five highest readings are averaged to obtain a realistic rebound number (Schmidt hardness). The hammer is always oriented perpendicular to the surface being tested. A unit dry weight must also be determined for the material being tested. Using the Schmidt hardness and the unit dry weight the uniaxial compressive strength of the sample can be estimated.

Tilt-type sliding-friction tests are also useful in estimating the shear strength of fractures. Samples can be obtained from outcrops or rock core. A representative sample is tilted and the angle at which the top of the sample slides relative to the bottom is measured. Both wet and dry surfaces should be tested. The weight, thickness, and approximate dimensions of the sample parts also are recorded. A friction angle can be estimated in a similar manner using three pieces of core. Two representative pieces of core are used as a base and the third piece is placed on top. The base is then tilted until the top piece of core slides and this angle is measured.

Pocket penetrometers may be used to estimate the strength of soil-like fillings or surfaces. The surface or a filling is penetrated by the penetrometer to the line on the penetrometer (about a quarter of an inch) and the approximate compressive strength is read directly from a calibrated scale on the penetrometer.

Example Descriptions of Fractures

The examples which follow are presented to show a representative format when recording data. Actual descriptions vary and depend on whether the observations were recorded from exposures, drill core, or detailed joint surveys. Data report descriptions of discontinuities should be expanded to provide ranges and typical characteristics or additional significant data for each set or individual fractures from all observations.

Drill Core.—The following SI metric example is taken from a log of a rock core interval from a vertical drillhole; in an angle hole, orientation would be recorded as inclination from the core axis:

> ". . . Moderately to slightly fractured (35% bedding joints, 65% joints). Core recovered in 210 to 730 mm lengths, mostly as 300 mm lengths. Bedding joints dip 30 to 35°; widely spaced (SP3) at 370 to 790 mm, avg 580 mm; 29 are tight, 6 are open; all are clean; 20 are moderately rought (R3), 15 are slightly rough (R4); oxidation penetrates 30 mm from surfaces (W4); all surfaces can be scratched by moderate knife pressure (H4). Joint set A dips 50 to 75°, mostly 60 to 65°, normal bedding; very widely spaced (SP2) at 0.9 to 1.2 m, avg 1m; 3 are open, 1 is tight and 9 are tight and headed by 3 to 30 mm thick, fresh (W1), very hard (H2), quartz-calcite fillings; the 3 open joints are clean, slightly rough (R4), oxidation stains penetrate 60 mm from surfaces (W4) which can be scratched by light to moderate knife pressure, all 3 show evidence of waterflow (W6) . . . ."

Exposure Mapping.—An example of fracture descriptions for an exposure (using English units) follows:

> "Joint set A-1 strikes N. 20-38° W., mostly N. 20-25° W.; dips 50-65° NE, averages 54° NE. Very widely spaced (SP2), 3.8 to 7.3 ft apart, mostly 5 ft apart; most have moderately to highly continuous (C3 to C4) 25 to 55 ft trace lengths. Approx. 60% are open to moderately wide (03 to 04), ranging in openness from 0.1 to 0.3 ft, remainder are tight to slightly open (00 to 01). Approx. 10% of the joints contain thin, hard quartz fillings, 25% are clean, and 65% contain firm fat clay (CH) fillings which can be indented with thumbnail. All rock surfaces are moderately weathered with dendritic iron oxide staining which can be scratched with light to moderate knife pressure. Most surfaces are slightly rough (R4) and undulatory, approx. 20% are rough (R-2) and planar. Undulations have wavelengths of 10 to 20 ft, average 15 ft and amplitudes range from 0.2 to 0.5 ft. Clean joints are dry but show evidence of moisture flow (M3), most clay filled joints are damp but show no evidence of flow (M4)."

Fracture Survey.—Statistical evaluations are often valuable to collect and analyze joint properties. This can be readily accomplished using fracture survey techniques. Data sheets are compiled with appropriate columns for recording the data, a traverse distance and direction are established, and all pertinent data are measured and recorded. Data are analyzed using statistical methods. Refer to Chapter 9 for detailed descriptions of discontinuity surveys.

Descriptions of Shears and Shear Zones

Shear, fault, and associated terminology are defined at the beginning of this chapter. The following presents a method to classify shears, shear zones and their associated features, as well as a format to describe and quantify their physical characteristics, and example descriptions. For each discussion, the word "fault" can be substituted for "shear."

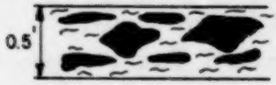
Identification or Naming of Shears

Significant shears should be named for ease of identification in logs of exploration, mapping of exposures, interpretations on geologic drawings, discussion in reports, sample identification, and design treatment. Identification of a shear or shear zone by letter/number designation, such as S-9 (shear zone No. 9) or F-1 (fault zone No. 1), is recommended. Major splays may be identified by an appropriate combination of letters and numbers such as S-1a or F-2c. Shears also may be named by their location such as "powerplant shear," "Salt Creek Shear zone," or "left abutment fault" if only a few shears are present in the study area.

Uniform and Layered Shear Zones

The identification and correlation of shears and shear zones from multiple, but rather discrete observations in boreholes, trenches, and limited outcrops are often difficult. The identification and description of shear and shear zones components and their physical characteristics are necessary to both assist in correlating observations and for design analyses. Together with physical measurements of attitude and thickness, the description of the component parts or layers of a shear may be used for correlation in much the same way that geophysical signatures or lithology are used to identify certain stratigraphic units.

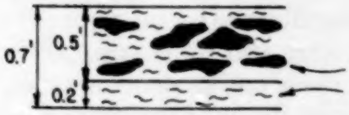
The composition of a shear or shear zone at each exposure can be described as either uniform or layered. Illustrated on figure 5-4 is an 0.5-foot (150 mm) thick uniform shear which is composed of 40 percent breccia distributed relatively uniformly throughout 60 percent clay gouge. Gouge and breccia are defined above. Although the shear contains two components, clay gouge and brecciated fragments, they are distributed uniformly.



Components
60% clay gouge
40% breccia (fragments)

Figure 5-4. — Uniform shear zone.

In contrast, a layered shear zone is composed of two or more layers (zones) which differ significantly in composition or have differing physical properties. A layered shear zone could consist of components similar to the uniform shear described above and an additional 0.2-foot (60-mm) thick quartz vein along one contact as shown on figure 5-5.



Components
60% clay gouge
(1) 70% 40% breccia (fragments)
(2) 30% quartz vein with minor gouge

Figure 5-5. Layered shear zone (2 zones or layers).

A more complex layered shear zone might have an 0.1-foot (30-mm) thick chloritic gouge layer adjacent to the vein as shown on figure 5-6.

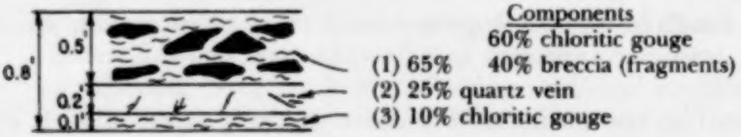


Figure 5-6. — Layered shear zone (3 layers).

Commonly, numerous small quartz-calcite or other mineral veinlets occur irregularly distributed throughout shears. The veinlets do not form distinct layers; therefore, they should be considered a percentage component of a uniform shear as illustrated on figure 5-7.

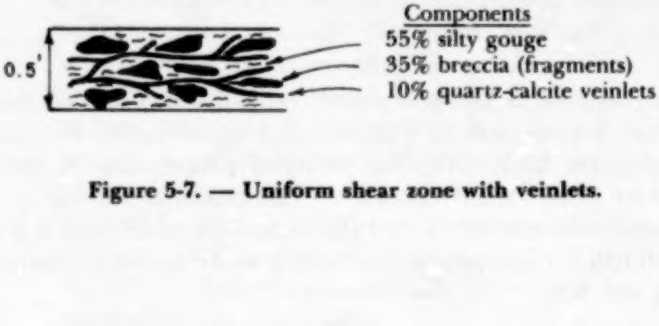
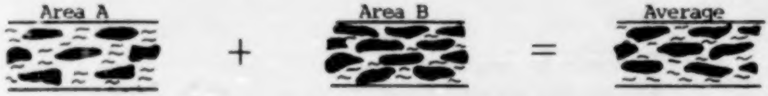


Figure 5-7. — Uniform shear zone with veinlets.

Shear zones may exhibit minor or major lateral variations in the percentages of components within short distances at an exposure. The shear zone illustrated on figure 5-4 consists of 40 percent clay gouge and 60 percent rock fragments and, because the various components are not arranged in layers, the shear is of the uniform type. On an adjacent tunnel, the same shear zone may consist of 40 percent clay gouge and 60 percent rock fragments. If the exposure is limited, as in most tunnels or exploratory trenches, the percentages of the various components should be averaged as illustrated on figure 5-8 and the average composition should be described and reported.



Area A	Area B	Average
60% clay gouge 40% breccia	40% clay gouge 60% breccia	50% clay gouge 50% breccia

Figure 5-8. — Uniform shear zone (composite).

Descriptors and Description Format for Shears and Shear Zones

For shears to be uniformly and adequately described, it is essential to include a brief description of each applicable item listed in the format and discussions which follow.

The recommended format for describing a shear or shear zone, both uniform and a layered zoned, is as follows:

- Thickness
- Attitude
- Composition

  Gouge

    Percent by volume
    Color
    Moisture
    Consistency (hardness/strength)
    Gouge composition
    Occurrence — layers or matrix

Breccia

    Percent by volume
    Fragment size(s)
    Fragment shape(s)
    Fragment surface characteristic
    Lithology
    Hardness

Other components

    Percent by volume
    Thickness
    Composition (mineralogy, texture, fracturing, etc.)

- Healing
- Zone strength
- Direction of movement (if determinable)

Thickness.—Report the true thickness of the shear or shear zone. True thickness can be measured directly or computed. Indicate an average figure for minor variations, as well as a range and average for significant variations. Do not include associated featured beyond the shear contacts (the shear-disturbed zoned), or intact blocks of rock around which the shear has bifurcated as components of is thickness.

Attitude.—Measure strike and dip in exposures and from oriented core, report dip in vertical core, and angle from core axis for inclined drill core. Report an average figure if only moderate variations are observed. Provide both a range and average if two distinct orientations are apparent.

Composition.—Report an average percentage for each description-format component. The various layers or zones or zoned shears may be indicated by use of bracketed numbers [i.e., shear 1(1), 1(2)]. Describe each individual layer or zone in the order it occurs as if each was a uniform shear.

1. Gouge.

    - Percentage.—Report an average percent by volume for each exposure or layer.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

DISCONTINUITY TERMINOLOGY

DISCONTINUITY - A collective term used for all structural breaks in geologic materials which usually are unhealed and have zero or low tensile strength. Discontinuities also may be healed and exhibit high tensile strength. Discontinuities comprise fractures (including joints), planes of weakness, shears/faults, and shear/fault zones. Contacts between various units also may be considered discontinuities.

FRACTURE - A term used to describe any natural break in geologic material excluding shears and shear zones. Additional fracture terminology is provided below.

SHEAR - A structural break where differential movement has taken place along a surface or zone of failure by shear; characterized by striations, slickensides, gouge, breccia, mylonite, or any combination of these. Often direction, amount of displacement, and continuity may not be known because of limited exposures or observations.

FAULT - A shear with significant continuity which can be correlated between observations; occurs over a significant portion of a given site, foundation area, or region; or is a segment of a fault or fault zone defined in the literature. The designation of a shear as a fault or fault zone is a site-specific determination.

SHEAR/FAULT ZONE - A shear that is expressed in relative terms of width. The zone may consist of gouge, breccia, or many related faults or shears together with fractured and crushed rock between the shears or faults, or any combination of these. In the literature, many fault zones simply are referred to as faults.

SHEAR/FAULT-DISTURBED ZONE - An associated zone of fractures and/or folds adjacent to a shear or shear zone where the country rock has been subjected to only minor cataclastic action and may be mineralized. If adjacent to a fault or fault zone, the term is fault-disturbed zone. Occurrence, orientation, and areal extent of these phenomena depend upon depth of burial (pressure and temperature) during shearing, brittleness of materials, and the stress envelope.

FRACTURE TERMINOLOGY

EXAMPLES SHOWN FOR CORE, BUT APPLICABLE TO ANY OBSERVATION

JOINT (JT) - A relatively planar fracture along which there has been little or no shearing displacement.

FOLIATION JOINT (FJ) OR BEDDING JOINT (BJ) - A relatively planar fracture which is parallel to foliation or bedding along which there has been little or no shearing displacement.

BEDDING PLANE SEPARATION - A separation along bedding after extraction or exposure due to stress relief or slaking.

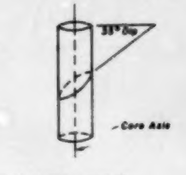
INCIPIENT JOINT (IJ) OR INCIPIENT FRACTURE (IF) - A joint or fracture which does not continue through the specimen or at least not seen with the naked eye. However, when the specimen is wetted and then allowed to dry, the joint or fracture trace is evident. When core is broken, it breaks along an existing plane.

RANDOM FRACTURE (RF) - A natural break (fracture) with a generally rough, very irregular, nonplanar surface which does not belong to a joint set.

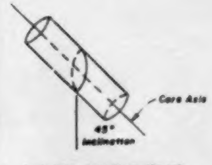
MECHANICAL BREAK (MB) - A break due to drilling, blasting, or handling. Mechanical breaks parallel to bedding or foliation are called Bedding Breaks (BB) or Foliation Breaks (FB), respectively. Recognizing mechanical breaks may be difficult. The absence of oxidation, staining, or mineral fillings, and often a hackly or irregular surface are clues for recognition.

FRACTURE ZONE (FZ) - Numerous very closely spaced intersecting fractures. Often fragmented core cannot be fitted together.

METHOD OF MEASURING DIP OF PLANAR DISCONTINUITIES, FOLIATION, AND BEDDING IN CORE



1. Vertical hole - true dip is measured and reported.

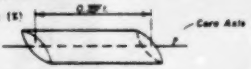


2. Angle hole - true dip usually not known; angle is measured from core axis and is called inclination.

ROCK QUALITY DESIGNATION (RQD)

$$RQD = \frac{\text{Sum of length of solid core pieces} \geq 0.33\text{ ft [4 in] (100 mm) long}}{\text{Length of the run in feet (m)}} \times 100$$

Expressed as percent (%)



FRACTURE FREQUENCY

FRACTURE FREQUENCY - The number of natural fractures occurring within a base length or core run. The number of fractures is divided by the length and is reported as fractures per foot or fractures per meter. Expressed as 3/m or 6/ft.

FRACTURE DENSITY

FRACTURE DENSITY - Based on the spacing of all natural fractures in an exposure or core recovery lengths in boreholes; excludes mechanical breaks, shears, and shear zones; however, shear-disturbed zones (fracturing outside the shear) are included. Descriptors for fracture density apply to all rock exposures such as tunnel walls, dozer trenches, outcrops, or foundation cut slopes and inverts, as well as boreholes. Descriptive criteria presented below are based on borehole cores where lengths are measured along the core axis, for other exposures the criteria is distance measured between fractures (size of blocks).

UNFRACTURED (FD0): No fractures.

VERY SLIGHTLY FRACTURED (FD1): Core recovered mostly in lengths greater than 3 feet (1 m).

SLIGHTLY TO VERY SLIGHTLY FRACTURED (FD2)*

SLIGHTLY FRACTURED (FD3): Core recovered mostly in lengths from 1 to 3 feet (300 to 1000 mm) with few scattered lengths less than 1 foot (300 mm) or greater than 3 feet (1000 mm).

MODERATELY TO SLIGHTLY FRACTURED (FD4)*

MODERATELY FRACTURED (FD5): Core recovered mostly in 0.3- to 1.0-foot (100- to 300-mm) lengths with most lengths about 0.6 foot (200 mm).

INTENSELY TO MODERATELY FRACTURED (FD6)*

INTENSELY FRACTURED (FD7): Lengths average from 0.1 to 0.3 foot (30 to 100 mm) with scattered fragmented intervals. Core recovered mostly in lengths less than 0.3 foot (100 mm).

VERY INTENSELY TO INTENSELY FRACTURED (FD8)*

VERY INTENSELY FRACTURED (FD9): Core recovered mostly as chips and fragments with a few scattered short core lengths.

---

* Combinations of fracture densities (e.g., Very Intensely to Intensely Fractured or Moderately to Slightly Fractured) are used where equal distribution of both fracture density characteristics are present over a significant interval or exposure, or where characteristics are "in between" the descriptor definitions.

FRACTURE SPACING

JOINT SET, OR FRACTURE SPACING DESCRIPTOR	TRUE SPACING
EXTREMELY WIDELY SPACED (SP1)	Greater than 10 ft (3 m)
VERY WIDELY SPACED (SP2)	3 to 10 ft (1 to 3 m)
WIDELY SPACED (SP3)	1 to 3 ft (300 mm to 1 m)
MODERATELY SPACED (SP4)	0.3 to 1 ft (100 to 300 mm)
CLOSELY SPACED (SP5)	0.1 to 0.3 ft (30 to 100 mm)
VERY CLOSELY SPACED (SP6)	Less than 0.1 ft (<30 mm)

FRACTURE CONTINUITY

CONTINUITY DESCRIPTOR	DISCONTINUITY LENGTH
DISCONTINUOUS (C1)	Less than 3 ft (<1 m)
SLIGHTLY CONTINUOUS (C2)	3 to 10 ft (1 to 3 m)
MODERATELY CONTINUOUS (C3)	10 to 30 ft (3 to 10 m)
HIGHLY CONTINUOUS (C4)	30 to 100 ft (10 to 30 m)
VERY CONTINUOUS (C5)	Greater than 100 ft (>30 m)

FRACTURE ENDS (JOINT SURVEYS)

FRACTURE ENDS DESCRIPTOR	DESCRIPTIVE CRITERIA
E0	Zero ends leave the exposure (both ends can be seen).
E1	One end of the fracture terminates in the exposure (one end can be seen).
E2	Two fracture ends do not terminate in the exposure (both ends cannot be seen).

FRACTURE OPENNESS OR FILLING THICKNESS

FILLING THICKNESS DESCRIPTOR	THICKNESS/OPENNESS	OPENNESS DESCRIPTOR
CLEAR (T0)	No film or coating	
	No visible separation	TIGHT (O0)
VERY THIN (T1)	Less than 0.003 ft [1/32 in] (<1 mm)	SLIGHTLY OPEN (O1)
MODERATELY THIN (T2)	0.003 to 0.01 ft [1/32 to 1/8 in] (1 to 3 mm)	MODERATELY OPEN (O2)
THIN (T3)	0.01 to 0.03 ft [1/8 to 3/8 in] (3 to 10 mm)	OPEN (O3)
MODERATELY THICK (T4)	0.03 ft [3/8 in] to 0.1 ft (10 to 30 mm)	MODERATELY WIDE (O4)
THICK (T5)	Greater than 0.1 ft (>30 mm) Actual thickness or openings recorded	WIDE (O5)

FRACTURE MOISTURE CONDITIONS

MOISTURE DESCRIPTOR	DESCRIPTIVE CRITERIA
M1	The fracture is dry. It is tight or filling (where present) is of sufficient density or composition to impede waterflow. Waterflow along the fracture does not appear possible.
M2	The fracture is dry with no evidence of previous waterflow. Waterflow appears possible.
M3	The fracture is dry but shows evidence of waterflow such as staining, leaching, and/or vegetation.
M4	The fracture or filling (where present) is damp, but no free water is present.
M5	The fracture shows seepage. It is wet with occasional drops of water.
M6	The fracture emits a continuous flow (estimate flow rate) under low pressure. Filling materials (where present) may show signs of leaching or piping.
M7	The fracture emits a continuous flow (estimate flow rate) under moderate to high pressure. Water is squirting and/or filling material (where present) may be substantially washed out.

FRACTURE ROUGHNESS

Refers to small scale asperities of surfaces, not large scale undulations or waviness.

STEPPED (R1): Near-normal steps and ridges occur on the fracture surface.
ROUGH (R2): Large, angular asperities can be seen.
MODERATELY ROUGH (R3): Asperities are clearly visible and fracture surface feels abrasive.
SLIGHTLY ROUGH (R4): Small asperities on the fracture surface are visible and can be felt.
SMOOTH (R5): No asperities, smooth to the touch.
POLISHED (R6): Extremely smooth and shiny.

FRACTURE SURFACE AND / OR FILLING ALTERATION AND HARDNESS

Descriptors for weathering or alteration of fracture surfaces and fracture fillings (excluding soil materials) are the same as those used for weathering and alteration of rock.

Descriptors for hardness/strength of fillings and/or fracture surfaces are the same as those presented for hardness of rock or consistency of soils.

DISCONTINUITY HEALING

TOTALLY HEALED (HL1) - All fragments bonded, discontinuity is completely healed or recemented to a degree at least as hard as surrounding rock.

MODERATELY HEALED (HL3) - Greater than 50 percent of fractured or sheared material, discontinuity surface or filling is healed or recemented; and/or strength of healing agent is less hard than surrounding rock.

PARTLY HEALED (HL5) - Less than 50 percent of fractured or sheared material, discontinuity surface or filling is healed or recemented.

NOT HEALED (HL6) - Discontinuity surface, fracture zone, sheared material or filling is not healed or recemented, rock fragments or filling (if present) held in place by their own angularity and/or cohesiveness.

SHEAR / FAULT DESCRIPTORS

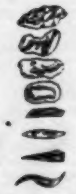
SHEAR / FAULT GOUGE CONSISTENCY

DESCRIPTOR	DESCRIPTIVE CRITERIA (Similar to consistency of soils.)
VERY HARD	Gouge cannot be broken with finger pressure; cannot be indented with fingernail.
HARD	Gouge can be broken with firm finger pressure; can be indented with fingernail; cannot be indented with thumb.
FIRM	Gouge can be easily crumbled; can be indented with thumb 1 to 5 mm.
SOFT	Gouge can be easily molded; can be penetrated with thumb 5 to 25 mm.
VERY SOFT	Gouge can be penetrated with thumb more than 25 mm.

SHEAR / FAULT MOISTURE CONDITIONS

The apparent moisture content of gouge is described as WET (visible free water); MOIST (damp but no visible water); and DRY (absence of moisture, dusty, dry to the touch). Moisture descriptors M1 through M7 may be used to describe the shear or shear zone.

BRECCIA SHAPES



Angular . . . .
Subangular . . . .
Subrounded . . . .
Rounded . . . .
Platy . . . .
Lens-shaped . . . .
Wedge-shaped . . . .
Contorted . . . .

ALWAYS THINK SAFETY

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
ENGINEERING GEOLOGY MANUAL
STANDARD DESCRIPTORS AND DESCRIPTIVE
CRITERIA FOR DISCONTINUITIES

GEOLOGY [illegible] TECHNICAL APPROVAL
DRAWN SUBMITTED
CHECKED APPROVED
CHIEF, DIVISION OF GEOLOGY
DENVER, COLORADO OCTOBER 1, [illegible]
40-D-6499

Figure 5-9.—Standard descriptors and descriptive criteria for discontinuities.

- Color.—Report color to help distinguish between several types of gouge or to indicate alteration. The Munsel Color System is to be used to record both the wet and dry color.

- Moisture content.—Describe he apparent moisture content upon initial exposure, using the following terms: wet (visible free water); moist (damp but without visible water); and dry (absence of moisture, dusty, dry to the touch).

- Consistency (strength/hardness). — Report the ease with which gouge can be worked by hand: Very soft [thumb penetrates gouge more than 1 in (25 mm) if the gouge occurs in a sufficient quantity]; soft [easily molded, penetration of thumb about 1 in (25 mm)]; firm [easily crumbled, can be penetrated by thumb up to 1/4 in (5 mm)]; hard (can be broken with finger pressure, no indentation with thumb, readily indented with thumbnail); and very hard (cannot be indented with thumbnail). Use a pocket penetrometer to estimate gouge strength.

- Gouge composition.—Report identifiable mineral types; talc, chlorite, mica. Otherwise, report the soil classification group name and/or symbol, such as CH, ML, lean clay, etc.

- Occurrence.—Describe how the gouge occurs, such as thin coatings on fragments, a matrix, or a layer.

2. Breccia.

- Percentage.—Report an average percent by volume for each exposure or layer.

- Fragment size.—Estimate or measure the dimension of the most common fragment sizes and report as a range. Use fractions of an inch and tenths of a foot, or metric equivalents.

- Fragment shape.—Unless the distribution of several shapes is nearly equal, report the most common shapes and degree of angularity as shown on figure 5-9, drawing number 40-D-6499.

- Fragment characteristics.—These should be included because they may affect or provide an indication of the strength of the zone or help to identify a particular zone in several exposures or observations. Descriptions should include striated, slickensided, polished, rough, chloritic coatings, and weathering.

- Lithology.—The identification of rock fragments (rock type) is essential, particularly if different from the surrounding rock mass or if several rock types are present in the zone. Indicate of fragments within the zone are altered.

- Fragments hardness/strength.—Describe how the average-size fragment can be broken across its least dimension using the following format: can be broken with (light, moderate, heavy) manual pressure or hammer blow.

3. Other Components (vein or dike material). — Describe any large veins or dikes which occur within the shear, either as a component of a uniform shear zone, usually occurring in the form of branching discontinuous veinlets less than ½-inch (13-mm) thick, or as a layer (zone) within a layered shear. Dikes or large veins should be included as a single layer of a shear zone if they are bounded by shears. Also, they should be described as a rock unit. If a shear occurs only along one border of a dike or vein, then the dike or vein should be described only as a rock unit.

- Percentage.—Report as an average percent by volume for the exposure or layer.

- Thickness.—Report as an average or range of thickness.

- Composition.—Provide a brief description of mineralogy and texture (e.g., leached, vuggy) only if important structurally or for identification. Terms for the degree of fracture density may be reported here if significant.

Healing.—Veins which compose distinct layers within a zoned shear probably accomplish insignificant healing. However, small veinlets which are components of a uniform shear zone and which actually form a bond between fragments tend to increase the strength of the shear zone [see following section]. Healing must be determined by attempting to separate fragments manually or using a rock hammer/pick. If fragments actually are bonded by some healing/cementing agent, the shear zone is described as partly healed (less than 50 percent of fragments bonded), mostly healed (more than 50 percent of fragments bonded), and totally healed (all fragments bonded by vein material).

Zone Strength.—When possible, the strength of the entire shear zone exposed in outcrops, tunnels, and exploratory trenches should be reported by the ease of which the sheared material can be dug from the exposure. The following guide is to be used: can be dug from (wall, floor, or outcrop) with (light, moderate, heavy) finger pressure or hammer blow. Strength should be reported for each significant layer of a shear zone.

Direction of Movement.—If determinable, the amount, direction, and type of displacement are to be reported. Type and direction of displacement (dip-slip, strike-slip, oblique-slip, normal, reverse, right-lateral) may be directly observable as evidenced by drag, tension fractures, striations, separation of "marker units," such as beds, dikes, veins, or other structural units. The amount of both horizontal and vertical separation and, if possible, a net-slip solution should be included in appropriate data submittals. Often, regional information (stress regimes) may be used to postulate displacement in the absence of site observations.

Example Descriptions for Shears and Shear Zones

The following are example descriptions for both a uniform and a layered shear zone; actual descriptions may depend on the type of observation.

A description, using SI metric, of a uniform shear in an angle hole could be described as:

> "21.30 to 22.31: Shear. 210 mm thick, upper contact inclined 40°, lower contact inclined 61° from core axis, averages 51°, parallel to bedding. Composed of approx. 15%, blackish-green, moist, soft, chloritic clay and 85% 2 to 10 mm thick platy and lens-shaped, subrounded,

> polished, intensely weathered (W7) metasandstone fragments. Fragments break with light manual pressure. Fragments partly healed by 1 mm thick quartz-calcite veinlets."

A layered shear zone in a vertical drill hole core could be reported in English units as:

> "118.6 to 121.9′: Shear zone. 2.3 ft thick, upper and lower contacts dip 40 to 45°, subparallel to foliation. Layer 1, upper 0.3 ft; consists of 45% green, moist, soft, chloritic clay gouge and 55% 0.05 to 0.1 ft subrounded, blocky, polished, fresh dike fragments; fragments break with moderate hammer blow. Layer 2 is 1.1 ft thick; consists of very intensely fractured, fresh dike which is partly healed by 0.01 to 0.3 ft-thick calcite veinlets and a 0.1 ft-thick, vuggy quartz-calcite vein at base of dike. Layer 3 is 0.5 ft of No Recovery. Layer 4, the lower 0.3 ft; consists of 70% gray, moist, firm, silty gouge and 15% 0.01 to 0.03 ft-thick, wedge-shaped, fresh, striated hornblende schist fragments, and 15% 0.02 ft-thick, angular, blocky, fresh quartz fragments. Fragments break with light hammer blow."

Description of Shear-Disturbed Zones

Fractures, fracture zones, drag zones, mineralized bedrock, and dikes or large veins along which one contact is sheared and which are associated with the shearing but are not themselves sheared or enclosed within a zone, are not included in the thickness of a shear or shear zone. However, the associated zone must be identified to adequately describe geologic conditions of engineering significance. For example, the shear-disturbed zone and an adjacent dike might be described as:

> ". . . The shear is bounded by a 1.5- to 4-ft wide shear-disturbed zone of very intensely to intensely fractured chloritized dike (FD8). (Describe fracture characteristics.) This zone averages 3 ft wide along the upper contact and 2 ft wide in the associated chloritized dike adjacent to the lower contact. Hydrothermal alteration consisting of epidote, chlorite, pyrite, and quartz extends irregularly outward 2 to 7 ft normal to the shear boundaries."

BIBLIOGRAPHY

[1] International Journal of Rock Mechanics Mining Science and Geomechanics abstracts, v. 15, pp 319-368, 1978.

[2] Proceedings of the Eighth Symposium on Rock Mechanics, University of Minnesota, 1967.

[3] Barton, N., R. Lien, and J. Lunde, Engineering Classification of Rock Masses for the Design of Tunnel Support: *Rock Mechanics,* v. 6, Springer-Verlag, pp. 189-236, 1974.

[4] Davis, George H., *Structural Geology of Rocks and Regions,* John Wiley & Sons, 1984.

Chapter 6

GEOLOGIC MAPPING AND DOCUMENTATION FOR DESIGN AND CONSTRUCTION

This chapter presents guidelines for the collection and documentation of surface and subsurface geologic field data for use in the design, specifications, construction, or maintenance of engineered structures. Surface geologic mapping is defined as the examination of natural and man-made surficial exposures of rock or unconsolidated materials, the systematic recording of geologic data from these exposures and the analysis and interpretation of these data in two- or three-dimensional format (maps, cross sections, and perspective [block] diagrams). The definition of subsurface geologic mapping is similar except the exposures are manmade and/or underground. The maps and cross sections generated from these data will: (1) serve as a record of the location of factual data; (2) present a graphic picture of the geologist's conceptual model of the study area based on the available factual data; and (3) serve as tools for solving three-dimensional problems related to the design, construction and/or maintenance of engineered structures.

Responsibilities of the Engineering Geologist

An engineering geologist must define, document, and evaluate site-specific geologic conditions relating to the design, construction, and maintenance of engineered structures. This responsibility also may include more regionally-based geologic studies, such as borrow-site investigations or regional reconnaissance mapping for specific purposes. An engineering geologist engaged in geologic mapping is responsible for:

Recognition of the key geologic features in a study area that will or could affect significantly a proposed or existing structure;

Integrating all the available, pertinent geologic data into a rational, interpretive, three-dimensional conceptual model of the study area; and

Presenting this conceptual model to design and construction engineers, to other geologists, and to contractors in a manner which they can all understand and use.

The process and responsibilities for engineering geology mapping are illustrated in figure 6-1.

The engineering geologist must realize that a mapping program for an engineered structure is a dynamic process of gathering, evaluating and revising geologic data and that the significance of these data, both to the structure an to further exploration, must be continually assessed. The initial exploration program for a structure is always based on incomplete data, and must be modified continuously as the site geology becomes better understood. The key to understanding the site geology is through interpretive geologic drawings, both maps and cross sections. These working drawings, periodically revised and re-interpreted as new data becomes available, are used by both geologists and engineers to assess continuously the effects of the site geology on the structure and to delineate areas where additional exploration is needed. Following final revision, these drawings are used in specifications and maintained in the technical record of the project.

Development of a Study Plan

Prior to mapping any project, a study plan must be developed. Depending on the complexity of the site geology, the nature of the engineered structure, and the level of previous studies, the study plan may be preliminary or comprehensive. Although elements of the plan may be modified, expanded or deleted as geologic data becomes available, the primary purpose of the study plan—coordination between all geologists and engineers working on the project—must be retained. Early study plan development and agreement to this plan by the geologists and engineers involved in the project is necessary to prevent the collection of unneeded, possibly costly data, and ensure needed data are available at the correct time in the design and construction process.

Scope of study.—The purpose and scope of a mapping project is a joint decision between the geologists and engineers

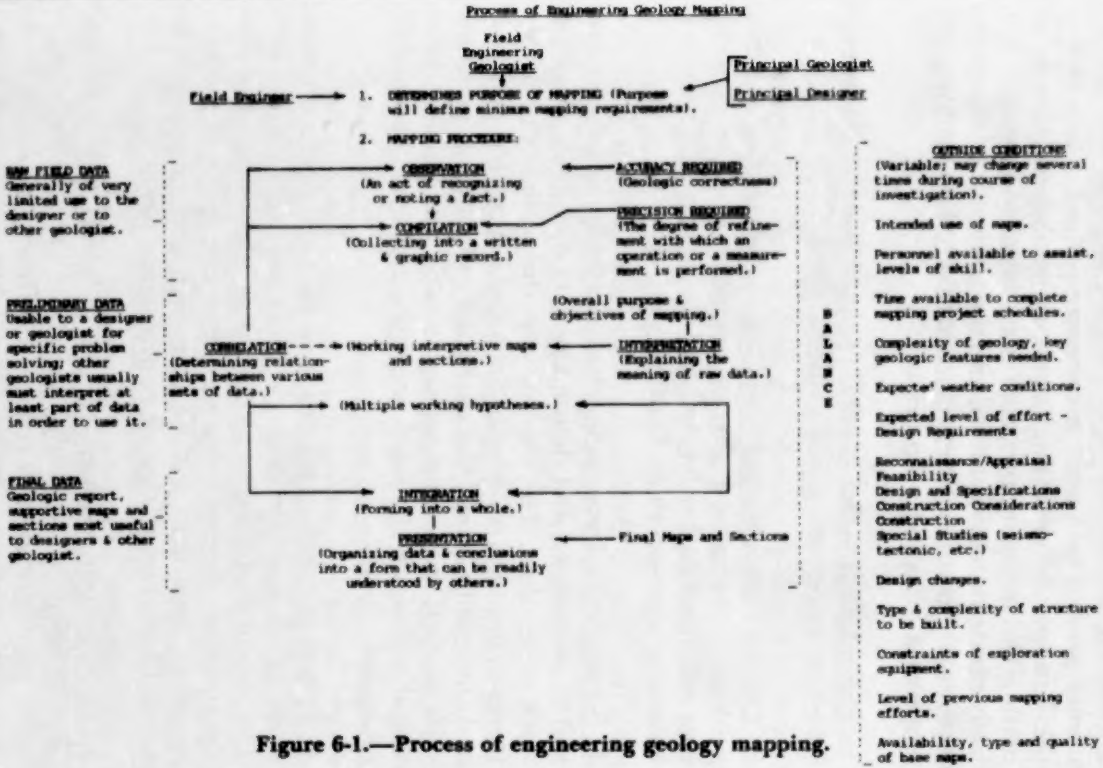

Process of Engineering Geology Mapping
Field Engineering Geologist
Field Engineer
1. DETERMINES PURPOSE OF MAPPING (Purpose will define minimum mapping requirements).
Principal Geologist
Principal Designer
2. MAPPING PROCEDURE:
RAW FIELD DATA
Generally of very limited use to the designer or to other geologist.
PRELIMINARY DATA
Usable to a designer or geologist for specific problem solving; other geologists usually must interpret at least part of data in order to use it.
FINAL DATA
Geologic report, supportive maps and sections most useful to designers & other geologist.
OBSERVATION
(An act of recognizing or noting a fact.)
COMPILATION
(Collecting into a written & graphic record.)
CORRELATION
(Determining relationships between various sets of data.)
(Working interpretive maps and sections.)
(Multiple working hypotheses.)
INTEGRATION
(Forming into a whole.)
PRESENTATION
(Organizing data & conclusions into a form that can be readily understood by others.)
ACCURACY REQUIRED
(Geologic correctness)
PRECISION REQUIRED
(The degree of refinement with which an operation or a measurement is performed.)
(Overall purpose & objectives of mapping.)
INTERPRETATION
(Explaining the meaning of raw data.)
Final Maps and Sections
BALANCE
OUTSIDE CONDITIONS
(Variable; may change several times during course of investigation).
Intended use of maps.
Personnel available to assist, levels of skill.
Time available to complete mapping project schedules.
Complexity of geology, key geologic features needed.
Expecte' weather conditions.
Expected level of effort - Design Requirements
Reconnaissance/Appraisal
Feasibility
Design and Specifications
Construction Considerations
Construction
Special Studies (seismotectonic, etc.)
Design changes.
Type & complexity of structure to be built.
Constraints of exploration equipment.
Level of previous mapping efforts.
Availability, type and quality of base maps.

Figure 6-1.—Process of engineering geology mapping.

assigned to the project. The purpose and scope of the mapping project is strongly influenced by the primary engineering and geologic considerations for the structure, the level of previous studies and overall job schedules. Time of year and critical dates for needed information also will have a great impact on the pace of data collection and the personnel needed to handle a mapping project. Discussion of these factors between engineers and geologists prior to initiating the mapping program is essential so that only critically needed data is obtained and the work can be completed in a timely manner. Items to consider when defining the scope of a mapping program are:

1. Study Limits.—Set general regional and site study limits based on engineering and geologic needs.

2. Critical Features and Properties.—Determine the critical geologic features and physical properties of site materials that will need to be defined and discuss the difficulties in collecting data on these features.

3. Schedules.—Determine schedules under which the work will be performed and define key data due dates. Prioritize work to be done. The time of year the mapping to be performed, the type of mapping required, available personnel and their skills levels, the availability of support personnel such as drill crews and surveyors, and budget constraints will all influence the work schedule and must be critically evaluated.

4. Extent of previous studies.—Collect and perform critical study of all available geologic literature to the study area. The extent and adequacy of previous Reclamation or non-Reclamation studies helps to define the types of mapping required, how data will be collected, and mapping scales needed based on design or construction needs.

5. Photography.—Consider use of aerial and terrestrial photography in the study. Extensive use of terrestrial or aerial photography will require a different approach to the mapping program. Define areas where terrestrial photogrammetry could aid mapping progress. Terrestrial photography of various types always should be considered an integral part of the final study record.

Specific Mapping Requirements.—This provides the basic procedural factors an engineering geologist should consider prior to starting any mapping project or portion of a mapping project.

1. Types of mapping required.—Define the types of mapping required and how data are to be collected, including special equipment needed to collect it. The types of mapping required depend on the type of structure that is to be built or rehabilitated, its size, the phase of study (planning through operation and maintenance), and the specific design needs.

2. Mapping scales and controls.—Define the required mapping scales for design or construction needs. Although finished maps can be enlarged photographically or reduced to any desired scale, in most cases map lettering will have to be redone for legibility. Selection of an adequate map scale at the beginning of a mapping project will save time and energy as well as helping ensure that the types of data needed can be portrayed adequately on the final drawings. Suggested map scales for various types of investigations will be listed under specific mapping techniques.

The accuracy and precision of geologic contacts on a map depend, in part, on the spatial control, both horizontally and vertically, of the base map. General base map controls are listed in order of decreasing accuracy and control: (1) Survey Control or Controlled Terrestrial Photogrammetry—geology mapped from survey controlled observation points or by plane table or stadia; (2) Existing Topographic Maps—control for these maps vary with scale. The most accurate are large-scale photogrammetric topographic maps generated from aerial photographs for specific site studies; (3) Uncontrolled Aerial/Terrestrial Photogrammetry—Photographic stretch is the chief source of error; (4) Brunton Compass—Tape Surveys—can be reasonably accurate if measurements are taken with care; and (5) Sketch Mapping—Practice is needed to make reasonably accurate sketch maps.

3. Specific nomenclature and definitions.—Establish a uniform nomenclature system with written definitions for rock

types, map units and map symbols used. The AGI *Glossary of Geology* [1] is the standard for geologic terms except where Reclamation has established definitions for its own needs. These definitions are discussed in Chapters 2 through 5.

4. Field equipment and techniques.—General geologic mapping equipment and techniques are discussed in published field geology manuals such as Lahee (1961) [2] and Compton (1967) [3]. Refer to these texts for discussions of suggested field equipment and general geologic mapping techniques.

5. Use of computers.—Computers are used during a mapping program in three basic ways: (1) to process and analysis voluminous map data (e.g. joint data); (2) as a tool in the analysis of basic geologic data (e.g. construction of preliminary or final plan and section views which incorporate previously entered geologic data); and (3) computer assisted drafting (CADD) of section and plan views. Each of the three basic uses of computers in geologic mapping require specialized software and possibly hardware. A decision on whether to use computers to assist in the reduction, analysis and drafting of the geologic data generated during a mapping program must be made early, as time will be needed to procure equipment and to adapt the software to the specific needs of the project. An additional reason for an early decision on the use of computers is that the tabulation form for field data will depend on whether data are to be entered into a computer data base or not, and restructuring these data at a later date could be costly and time consuming.

6. Right of way.—Right-of-way is need for any mapping of non-Bureau of Reclamation land and should be initiated early to prevent delay of the work. Although "walk on" permission usually is obtained easily, permission for trenching and drilling may take several months, especially if archaeological or environmental assessment is necessary.

7. Records.—Establish a systematic method of recording field observations, traverse data, outcrop data, and trench logs. Suggested sample field book formats will be shown under each section dealing with specific mapping procedures, but any format that allows clear representation of the field data is acceptable.

8. Geologic considerations.—The following are the key features that should be documented and evaluated during a mapping project. All may not be critical for a given mapping project, but all should be considered.

a. Lithology.—Differentiation between the various geologic deposits and lithologies in a study area is basic to geologic mapping. However, an engineering geologist is more concerned with the engineering characteristics of the unit than with its geologic definition and these characteristics should be the controlling factor in how geologic deposits are subdivided. For some engineering geologic purposes, it may be reasonable to consolidate geologic units with similar engineering properties into a single engineering geologic map unit. Depending on the needs of the mapping project, lithologic subunits may be defined jointly between the engineers and the geologists working on the job.

After the basic geologic subdivisions for a mapping job have been agreed upon, detailed descriptions of each subunit should be compiled and mapping symbols selected. Map unit definitions usually will apply specifically to the job or project area and normally will be modified as additional data are collected. Map symbols fall into three basic categories: (1) unit symbols; (2) structural symbols; and (3) accessory symbols. Unit symbols are the designators for the map geologic units and usually will apply only to the project area. Structural symbols represent geologic contacts, faults, attitudes of beds or faults, or folds and although somewhat standardized, must be defined for the project area. Accessory symbols are used to represent shafts, trenches, and drill holes and are generally standardized. American Geological Institute data sheets have a comprehensive tabulation of accessory symbols. For Bureau of Reclamation standard geologic map symbols, see drawing number 40-D-6490, figure 7-4, *Engineering Geology Office Manual*.

b. Geologic contacts.—Two different line types normally are used on geologic maps to denote the mappers confidence in the precision and accuracy of geologic contacts. These are solid and broken (dashed or dotted).

Solid contacts usually are used where exposures are excellent, such as a cleaned foundation invert or an area with nearly continuous outcrops. This line indicates the mapper is confident that the contacts are located with a prescribed degree of accuracy. Broken contacts are used where the mapper is unsure of the accurate location of the contact, i.e., when it is covered by thin slopewash deposits (dashed line), or where the contact is buried by deep surficial deposits (dotted line). Confidence levels, expressed in feet or meters, for both types of contacts should be stated clearly in the definition of the contact line. The mapper should keep in mind the type of geologic data being compiled and use the appropriate line. For proper line weight and lettering sizes, see figure 7-1, *Engineering Geology Office Manual*.

c. Discontinuities.—Discontinuities separate foundation materials into discrete blocks, which can adversely affect the stability and bearing capacity of the foundation. In cutslopes, intersecting discontinuities can form unstable wedges. Because of these weakening effects, the mapping and adequate description of discontinuities are critical in engineering geology studies. The various types of discontinuities and the terminology for describing their engineering properties are discussed in Chapter 5.

d. Weathering and alteration.—The mechanical and chemical alteration of foundation materials can significantly affect their stability and bearing strengths. An adequate delineation of weathering depths, extent of altered materials and the engineering properties of these weathered and altered materials is critical in engineering geologic mapping. Refer to Chapter 4 for definitions of weathering and alteration descriptors.

e. Water.—The location and amount of ground water to be expected in an excavation and how it can be controlled is critical to the overall success of a project.

f. Geomorphology.—Study of the present landforms in a project area can help in interpreting the underlying structures and the geologic history of the area. Knowledge of the geomorphic history is helpful to evaluate the relative age of suspected active faults.

g. Vegetation indicators.—Differences in vegetation types and patterns provides indirect data on lithologies, discontinuities, weathering, ground water and mineralization. The water holding capabilities of soils and weathered rocks developed on specific lithologies (e.g. shale vs. sandstone) many times will control the types of vegetation that grow on them. Mineralization affects soil chemistry, and may limit vegetation to types tolerant of highly acidic soils or high concentrations of trace elements. Vegetation seeking ground water moving up major joints and faults will form vegetation linears that are highly visible on aerial photographs, particularly color infrared photographs. In most locations, local conditions will have to be assessed to use vegetative indicators effectively.

h. Cultural features (man-made).—Cultural features such as water, gas or oil wells, road cuts or foundation excavations can provide surface and subsurface data, and should be reviewed early in the mapping project. When additional data collection through trenching and core drilling programs are considered, care must be taken to prevent the disruption of buried utilities (water, gas, electrical or sewage). Usually the utility companies will locate their lines.

i. Field checking.—Field checking by both mapper and supervisor is a critical part of the mapping process. Field checking after a map is complete allows the mapper to check the interpretations at a given location with the geologic concepts developed on the map as a whole. Field checking by the supervisor ensures that the basic field data are correct and conforms with project standards. Periodic field checking of previously mapped data can be useful as the mapper's concept of the site geology changes with the addition of new surface and subsurface data.

Surface Geologic Mapping

Detailed instructions for various types of engineering geologic mapping are presented are divided into two parts, mapping prior to after construction and mapping during construction. In general, these instructions are for: (1) general mapping requirements for the job; (2) suggested equipment; (3) specific preparations needed for the job; (4) type of documentation needed; and (5) special considerations that this type of mapping may require.

Feasibility Preconstruction Geologic Mapping

Site Mapping

General requirements.—Relatively detailed site geologic mapping studies generally are done for most Reclamation structures. Site mapping requirements are controlled by numerous factors, the most important of which are the type and size of structure to be built or rehabilitated, the phase of study (planning through operation and maintenance), and the specific design needs.

Site mapping studies for major engineering features should be performed within an approximate 5 mile radius of the feature, with smaller areas mapped for less critical structures. These studies consist of detailed mapping and a study of the immediate site, with more generalized studies of the surrounding area. This approach allows an integration of the detailed site geology with the regional geology. The overall process of site mapping is a continuous progression from preliminary, highly interpretive concepts based on limited data, to final concepts based on detailed, reasonably well-defined data and interpretation. This progression builds on the previous step using more detailed and usually more expensive methods of data collection to acquire additional and better defined geologic data. Typically, site mapping is performed in two phases: (1) preliminary surface geologic mapping; and (2) detailed surface geologic mapping. All site mapping studies begins with preparation of a preliminary surface geologic map (Phase 1) which delineates surficial deposits and existing bedrock exposures. The preliminary surface geologic map is the used to select sites for dozer trenches, backhoe trenches, and drill core holes (Phase 2). Surface geologic maps are then re-interpreted based on the detailed surface and drill core data. If required, detailed subsurface geologic data are also obtained from exploratory shafts, tunnels, and raises.

Suggested equipment.—Standard geologic field mapping equipment.

Preparation.—Whether a site mapping program is completed in one field season or over several years, the overall project schedule is critical. A critical assessment must be made of the time available for the mapping program, the skills and availability of personnel to accomplish the work, weather conditions, and budget constraints.

Documentation.—Site mapping data are documented on geologic maps and cross sections generated during the study. These drawings fall into two general categories—working drawings and final drawings. Working drawings serve as tools to evaluate and analyze data as it is collected and to define areas where additional data are needed. Analysis of data in a three-dimensional format is the only way the geologist can arrive at an understanding of the site geology, and it is critical these drawings be generated early in the mapping study and continuously updated as the work progresses. These drawings are used for preliminary data transmittals. Final drawings are generated late in the mapping program, after the basic geology is well understood. Although working drawings may be finalized, many times new maps and cross sections are generated to illustrate specific data that were not available or well understood when the working drawings were made. These drawings serve as a record of the investigations for specifications or technical record reports. Site mapping documentation requirements will be discussed in two phases: (1) preliminary surface geologic mapping; and (2) detailed surface geologic mapping.

1. Preliminary Surface Geologic Mapping (Phase 1).—The purpose of preliminary surface geologic mapping is to define the major geologic units and structures in the site area and the general engineering properties of the units. Suggested basic geologic maps are a regional reconnaissance map at scales between 1 inch = 2,000 feet to 1 inch = 5,280 feet (1:24,000 to 1:62,500), and a site geology map at scales between 1 inch = 20 feet to 1 inch = 1,000 feet (1:250 to 1:12,000). Scale selection depends on the size of the engineered structure and the complexity of the geology. Maps of smaller areas may be generated at scales larger than the base map to illustrate critical data. Cross sections should be made at the same scale (horizontal and vertical) as the base maps unless specific data are better illustrated at an exag-

gerated scale. Exaggerated scale cross sections are generally not suited for geologic analysis because the distortion makes projection and interpretation of geologic data difficult.

Initial studies generally are a reconnaissance-level effort, and the time available to do the work usually is limited. Initially, the mapper is dependent upon previous geologic studies in the general site area that have been compiled by Reclamation, other agencies, or individuals. Obtain and review these studies, possibly field checking them for adequacy and adding data from new exposures. Initial base maps usually are generated from existing topographic maps, but because most readily available topography is unsuitable for detailed studies, site topography at a suitable scale should be obtained if possible. Existing aerial photographs can be used as temporary base maps if topography maps are not available. Sketch mapping and Brunton/tape surveys of surface geologic data can be done if survey control is not available. Good notes and records of outcrop locations and data are important to minimize re-examination of previously mapped areas. Photography is a highly useful tool at this stage in the investigation, as photos can be studied in the office for additional data. Only after reasonably accurate surface geology maps have been compiled can other investigate techniques such as trenching and core drilling be used to full advantage. For some levels of study, this phase may be all that is required.

2. Detailed Surface Geologic Mapping (Phase 2).—The purpose of detailed surface geologic mapping is to define the regional geology and site geology in sufficient detail so that engineering geologic questions critical to the structure can be answered and addressed. Specific geologic features critical to this assessment have been identified and studied, and detailed descriptions of the engineering properties of the site geologic units are compiled. Project nomenclature should be systematized and standard definitions used. Suggested basic geologic maps are similar to those discussed under Phase 1 studies, although drawing scales may be changed based on the results of the initial mapping program. Maps of smaller areas may be generated to illustrate critical data at scales larger than the base map.

The preliminary surface geology maps generated during Phase 1 studies are used to select sites for dozer trenches, backhoe trenches, and drill core holes. Because core drilling is expensive, the initial work done under this phase should concentrate on using dozer trenches and/or backhoe trenches to further delineate and define the surface geology. As the surface geology becomes better defined, drill hole locations can be selected to help clarify multiple geologic problems. Detailed topography of the study site should be obtained if not obtained during the initial investigations. Data collected during the Phase 1 investigations should be transferred photographically to the new base maps, if possible, to save drafting time. Field mapping control is provided primarily by the detailed topographic maps, supplemented by survey control if available or Brunton/tape survey if it is not. Small scale aerial photographs of site area flow to obtained detailed topography are useful in the geologic mapping.

Dozer Trench Mapping

General Requirements.—Dozer trenches are cut to expose rock or unconsolidated materials below surficial deposits and major surface creep. Walls normally should be excavated as vertical slopes free of narrow benches and loose debris. In most cases the trench should be at least 12 feet deep. Upon completion of excavation, floors must be cleaned below any depth of ripping; loose rubble should be removed and a new surface exposed. Structures such as contacts and shear zones must be traceable from wall into floor for optimum determination of their nature and attitude. The geologist is responsible to ensure the dozer operator produces a safe finished trench that meets these standards. Evaluate the need for protective trenching. Usually, fencing is required even if the trench is on Reclamation land. If the trench is not on Reclamation land or if livestock are present, fencing of the trench with four strands of barbed wire may be required. After trench logging is completed, decide whether to leave the trench open or to backfill it. At sites with complex geology it is desirable to leave the trench open, as this allows re-interpretation of the trench in light of newly acquired data. Backfilling of the dozer trench may be necessary if it is not on Reclamation land or where an open trench would be a safety hazard. Generally, all trenches should be backfilled and tamped prior to filling the reservoir.

Suggested Equipment.—Standard field equipment. Additional equipment needed includes hard hat, plastic flagging, nails, wooden stakes, surveyors chain (feet or meters) and log book. Use shovel and whisk broom for cleaning trench exposures and a Brunton tripod for more accurate trench bearings.

Preparation.—Prior to working in a dozer trench, the geologist should walk through the excavation to examine the trench walls for failure planes (obvious or incipient) or loose materials. These should be removed before mapping starts. An examination of the whole trench should be made at the start of each work period. At initial mapping, a baseline should be laid out along the toe of the trench wall. Because dozer trenches generally are not straight, the trench should be divided into a series of straight segments with stations established at each point where the trench changes direction. These stations are lettered (e.g. A, B, etc.) from left to right when facing the trench wall. Each station should be marked by a 1-inch × 2-inch × 14-inch (25 × 50 × 350mm) wooden stake, tied with flagging, and marked with the trench number and station letter (e.g. DT-12A). Flagging strips should be nailed to the wall approximately 6 feet (2 m) vertically above the station for another reference point in case minor sloughing buries the stake.

Documentation.—Record trench logs, along with names of the field party and date, in a field book. Record book DI-9, Department of Interior (7-1/2 × 10 inches) is suggested, with trench logged at a scale of 1 foot per square (1 inch = 6 feet or 1 inch = 2 meters). Determine and record the bearing (preferably using a Brunton tripod), slope distance, and slope angle between each station. Survey the coordinates and elevations of each station. Orient the log book so the sketch and description may be viewed together (see fig. 6-2). Sketch the walls and floors across the top page of the open log book. Mark the baseline at 5-foot (1.5 m) intervals and draw a single "hinge line;" wall above, floor below. Determine the vertical heights of the trench walls at each station, and between stations if the profile or thickness of overburden changes between stations.

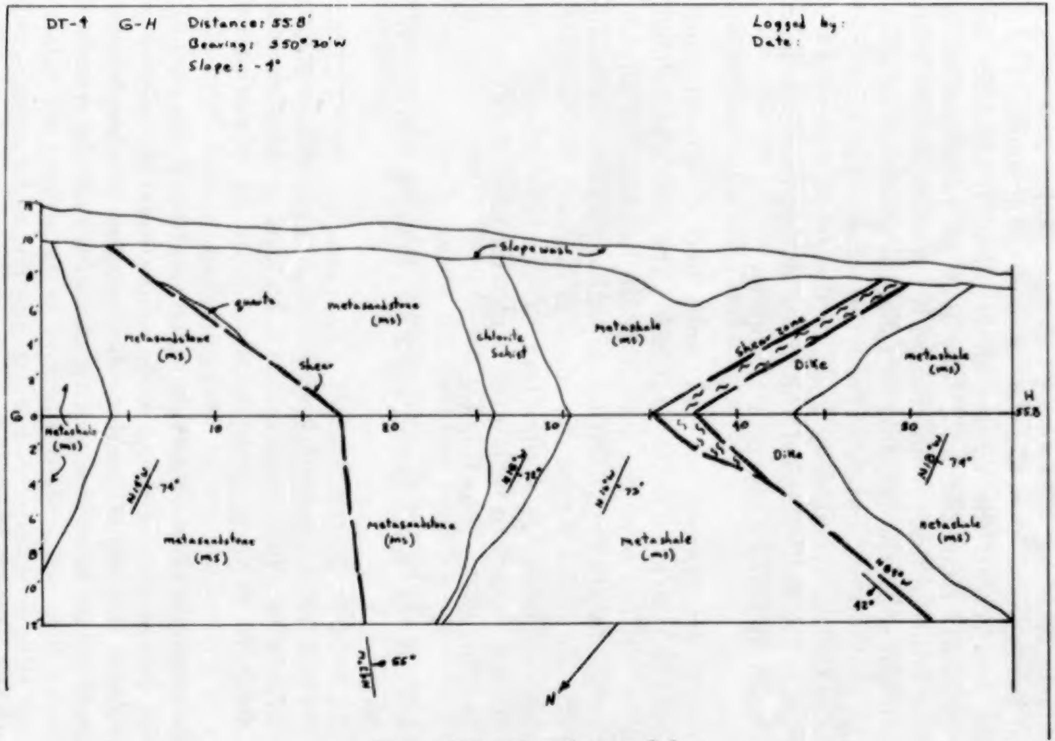


Figure 6-2.—Sample trench log.

Sketches must be as accurate as possible and illustrate the field relationship of geologic units and structures. Use nails and flagging strips to mark obscure contacts or other features for ready reference during logging. Designate geologic units by name and symbol. Accurately plot the attitude of contacts, bedding, foliation or cleavage, faults, shear zones, and joints where they are determined using standard symbols, and record the written description. If attitudes are determined from the wall, they may be projected along strike into the floor if no change is apparent in the floor. Note and show the bedding or foliation wherever relationships are complex and differ from the recorded attitude (i.e., where surface creep, drag folds, or disturbed zones are exposed in the wall). Record unit attitudes that may have been affected by surface creep or slumping.

Written descriptions of rock units and structural zones should be restricted to the page below the sketch and should not be written over the sketch. Main heading for written descriptions are restricted to mappable geologic units. Intervals are noted where the contacts intersect the baseline. Indent subheadings within text to describe lithologic or structural variations within the mappable unit. An example of heading order is as follows:

DT-58, Sta. B–C, Distance – 27.5′, Bearing – S. 45° W., Slope + 2
22.5–50.0′: Metasediments .... (description)
39.9–41.0′: Chlorite Schist B .... (description)
47.5–49.0′: Talc Schist.............................. (description)
48.2–48.4′: Shear Zone .... (description)

The example illustrates both sketch and rock descriptions from a page of a field log. Rock units should be colored to complete the log. Consider photography to complement trench log or to record specific details within the trench.

Backhoe Trench Mapping

General Requirements.—Backhoe trenches are excavated to expose rock or unconsolidated materials below surficial deposits and major surface creep. Generally backhoe trenches are excavated at sites which must be returned to near-original conditions and where dozer trenching would produce unacceptable damage. Backhoe trenches often are excavated in the floor or an existing dozer trench. Walls should be excavated as vertical slopes free of narrow benches and loose debris. In most cases the trench should be about 3 to 3-1/2 feet wide (1 m) (width of standard backhoe bucket), 10 to 12 feet (3 to 3.6 m) deep and slopes at one end for easy access and to allow for drainage of groundwater. Upon excavation completion, hydraulic trench shores are placed and pressurized or wooden shores constructed to support the trench walls. Shore construction and spacing must meet the standards outlined in Reclamation's Construction Safety Standards manual. At no time should personnel enter unshored portions of the trench. The geologist who oversees the excavation of the backhoe trench is responsible for the construction of a safe, stable trench.

After trench logging is completed, decide whether to leave the trench open or to backfill it. At sites with complex geology leave the trench open, if possible, as this allows reinterpretation of the trench in light of newly acquired data. However, backhoe trenches are prone to sloughing with time, even when supported, and backfilling of the trench may be necessary from safety reasons. The coordinate and elevation of each end of the backhoe trench should be determined by third order survey, if possible, prior to backfilling.

Suggested Equipment.—Standard field equipment. Additional equipment needed includes a hard hat, large knife, flat-blade pick or army trenching tool to clean off trench walls, whisk broom, nails, flagging, twine, small string level, 100 foot (30.48 m) long surveyor's chain and map board or log book. The type of backhoe needed depends on how consolidated the material is, site accessibility, and depth to be excavated. Most of the larger, rubber-tired backhoes are suitable for excavation of typical trenches, but well consolidated material, steep site terrain or trench depths over about 12 feet (3.6 m) may require a larger track-mounted backhoe.

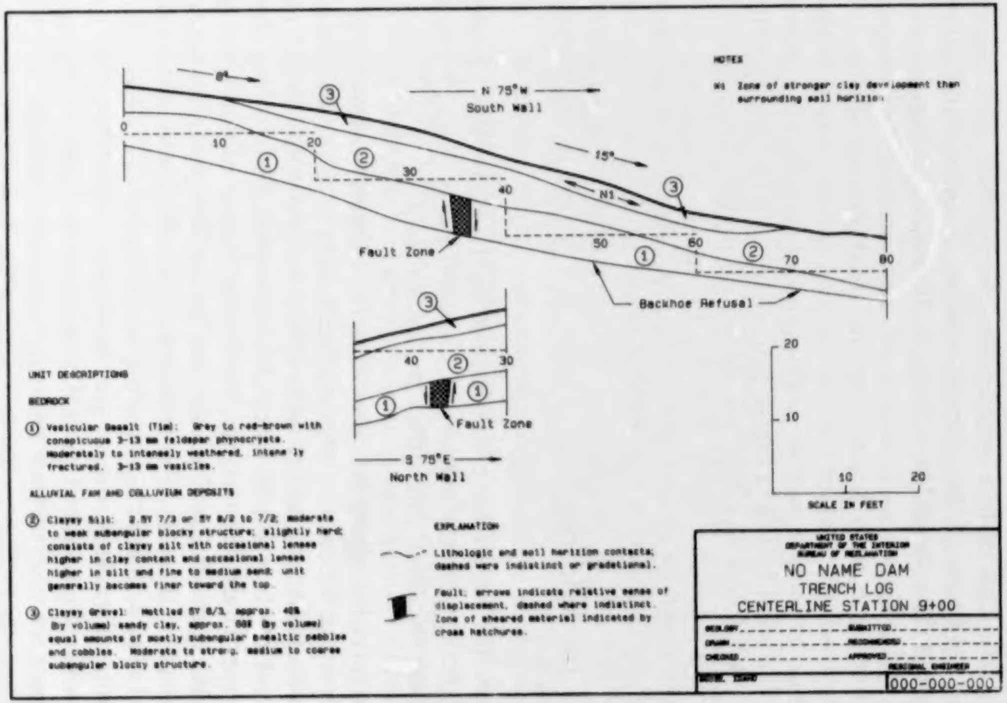
Preparation.—Each day prior to working in a backhoe trench, the geologists should walk the top of the trench along both sides and examine the trench walls for incipient fractures or loose materials, particularly within the surficial materials. These should be removed before work commences. Hydraulic trench shores should be checked visually for leakage and for loss of pressure by pushing on them with a foot. Re-pressure any loose shores and replace leaking shores. As mapping procedures within the backhoe trench, the stability of each shore should be checked before the mapper's weight is put on it, particularly if the shore is to be used to examine the upper trench wall or to climb out of the trench.

Prior to logging a backhoe trench, it must be cleaned. During excavation, the backhoe bucket will smear clay and silt along the walls, obscuring structural and stratigraphic relationships. This smeared zone may be anywhere from a fraction of an inch thick to several inches thick, depending on the amount of fines in the material excavated. The smeared material can be removed by chipping with a large knife, flat-bladed pick or army trenching tool. If the trench is excavated in reasonably consolidated material and the trench is free draining, a high pressure water jet will remove this material. Both walls should be spot cleaned and examined prior to major cleaning to determine which wall exhibits the best geologic data. Usually only one wall is completely cleaned; the other wall is spot cleaned during trench logging to expose another view of critical features or relationships. After a wall is cleaned, a horizontal base line is established. The baseline is run at about eye level and constructed by stringing twine between nails driven into the cleaned trench wall. The twine is leveled using a small string level (available in most hardware stores) prior to driving nails. When the baseline becomes either too high or too low for comfortable measurements, a vertical offset of the string line is made and the baseline continued at the new horizon. In complex, critical areas where accurately located contacts are needed, a string grid with horizontal and vertical elements can be constructed off the baseline to assist in mapping.

Documentation.—The scale and format selected for logging a backhoe trench depends on the type of data needed and the amount of detail to be illustrated. Typical backhoe trench log scales are between 1"=5' and 1"=10', but scales of 1"=1' may be required in critical areas to adequately show structural and stratigraphic details. If trench geology is not complex, record book DI–9, Department of Interior is suggested, with trench logged at a scale of 1 foot per square (1 inch = 6 feet). The log book should be oriented so the sketch and description may be viewed together. The names of the field party, date, trench number, location, and other pertinent data should be recorded. If trench geology is complex and a larger scale is desired, cut sheets of grid paper attached to a map board may be used. These sheets are usually redrafted after trench logging is completed. If the backhoe trench is wet or wall material is sloughing down onto the map board, a blank grid sheet can be taped to the map board and overlain by sheets of mylar. Trench data sketched onto the mylar will not be smeared as easily and the sheets can be erased without tearing. Another advantage using mylar sheets is that Ozalid prints of the sheets can be made for use in preliminary data transmittal or as check prints for field checking. Figure 6-3 shows a completed trench log.

Because the log sheets are separated easily, each sheet should be marked with the names of the field party, date, trench number, location, and other pertinent data.

Begin trench logging by recording the trench bearing (preferably using a Brunton tripod). Stationing is not used unless the trench has segments with different bearings. Begin at one end of the trench, place the surveyors chain along the horizontal base line string. Vertical distance of the trench wall above and below the base line should be measured every 10 feet (3 m) or so and the trench outlines sketched. Sketches must be as accurate as possible to illustrate the field relationship of geologic units and structures. Use flagging to mark obscure contacts or other features for easier logging. Intervals for the various geologic units and features are to be noted where the contacts intersect the baseline. Contacts above and below the baseline are located by two measurements, the vertical distance from the baseline and baseline distance, and sketched onto the log. Geologic units should be designated by name or symbol. Symbols to illustrate the attitude of contacts, bedding, foliation or cleavage, faults, shear zones, and joints should be drawn at the point where



NOTES

N1 Zone of stronger clay development than surrounding soil horizion.

UNIT DESCRIPTIONS

BEDROCK

① Vesicular Basalt (Tim): Grey to red-brown with conspicuous 3-13 mm feldspar phynocrysts. Moderately to intensely weathered, intense ly fractured. 3-13 mm vesicles.

ALLUVIAL FAN AND COLLUVIUM DEPOSITS

② Clayey Silt: 2.5Y 7/3 or 5Y 8/2 to 7/2; moderate to weak subangular blocky structure; slightly hard; consists of clayey silt with occasional lenses higher in clay content and occasional lenses higher in silt and fine to medium sand; unit generally becomes finer toward the top.

③ Clayey Gravel: Mottled 5Y 6/3, approx. 40% (by volume) sandy clay, approx. 60% (by volume) equal amounts of mostly subangular basaltic pebbles and cobbles. Moderate to strong, medium to coarse subangular blocky structure.

EXPLANATION

Lithologic and soil horizion contacts; dashed were indistinct or gradational.

Fault; arrows indicate relative sense of displacement, dashed where indistinct. Zone of sheared material indicated by cross hatchures.

Figure 6-3.—Sample of completed trench log.

they are determined and also recorded in the written description. Bedding or foliation should be depicted and noted wherever relationships are complex and differ from the recorded attitude (i.e., where surface creep, drag folds, or disturbed zones are exposed in the wall). Record attitudes on units that may have been affected by surface creep or slumping should be so noted.

Written descriptions of rock units and structural zones should be restricted to the area below the sketch and should not be written all over the sketch. Main headings for written descriptions are restricted to mappable geologic units. Description format is similar to that discussed for dozer trench mapping. After trench logging is completed, geologic units should be colored to complete the log and the trench field checked. Photography may be used to complement trench log or to record specific details within the trench, but the limited space and poor lighting conditions in a backhoe trench many times make it difficult to obtain satisfactory photos. Generally, cameras capable of close-up focusing and loaded with fast film work best. Photographs taken while standing at the top of the trench generally are not satisfactory because of contrasting lighting and poor perspective.

Construction Geologic Mapping

The purpose of geologic mapping during construction is to: (1) identify and delineate construction-related needs and problems, either potential or actual, in a timely manner; (2) verify and better define geologic interpretations made during design studies, particularly for critical geologic features and properties; (3) determine if the geologic conditions are as interpreted during the design phase and to ensure the principal designer that the actual conditions revealed are as interpreted. If those conditions are not as interpreted then design modifications may be required; and (4) provide a record of as-built conditions in the event that litigation or operational problems might occur.

To obtain meaningful data for mapping during construction, cooperation and coordination between the Contractor and the Project Construction Engineers' staff is required. The field geologist must prioritize the work and when the specific area is ready for mapping and approval, the staff and surveyors (if required) should accomplish the work as quickly as possible. Photographs should be taken (slides are preferred—prints can be made on an as needed basis)—purchase and use whatever lenses that are appropriate to accomplish the work. Label and date all photographs!

Your staff should be alerted to possible hazards that might occur during mapping. Safety precautions should be pointed out during the regular safety meetings.

Large Excavation Mapping

General requirements.—The purpose of geologic mapping of a site during construction is to: (1) delineate construction-related needs and problems, either potential or actual, in a timely manner; (2) verify and better define geologic interpretations made during design studies, particularly for critical geologic features and properties; and (3) provide a record of as-built conditions. The Construction Considerations, prepared by the Denver Office should contain guidelines for the mapping of a specific feature as an appurtenant structure. Determine scope and detail of mapping required at each portion of the site, then prioritize the work. Determine suitable scale of mapping. Suggested scales—detailed foundation invert map scale of 1 inch = 5 feet to 1 inch = 50 feet (1:50 to 1:600), generalized foundation invert map-scale 1 inch = 20 feet to 1 inch = 100 feet (1:20 to 1:1,000). For needed controls, consider the use of photography both for record and for base maps. Detailed, as-built foundation geology maps are used in final design modification, as a final record, and for use in possible future O&M problems. Mapping usually is done on detailed topographic base maps generated from survey control. Geology points are flagged and surveyed by a survey crew. Use terrestrial photography and photogrammetry as a mapping aid. Consider general photography for inclusion in the final construction report and as a part of the construction record. Slides are helpful for the Governments' case when presented in Claims Court. Use standard nomenclature and symbols both on maps and photographs but they should be consistent with those used in earlier studies. Use a systematic method of collecting mapping data, then work out the notes and compile these data into a useful and accurate geologic map. For critical areas, the map should be reviewed by the Principal Geologist as well as the Regional Geologist and other supervisory geologist.

Detailed, as-built geology maps for cutslopes may be required for use in delineating and solving major slope stability problems and in selecting general slope support systems where required. Recommended scale selection for detailed cutslope geology maps are: scale 1 inch = 10 feet to 1 inch = 50 feet (1:100 to 1:600), generalized cutslope geology maps use a scale 1 inch = 20 feet to 1 inch = 100 feet (1:200 to 1:1,000). Generally, mapped on detailed topographic base maps are generated from survey control. Geologic points may be flagged for survey by survey crews which are similar to foundation mapping (above) in other requirements.

Steep Slope Mapping

General requirements.—Define the purpose and goal for mapping. Know stratigraphy and structural geology prior to ascending slopes. Select scaling and safety equipment for specific areas.

Preparation.—Training for safety includes safety aspects of working while being suspended by ropes. Special training is required for various scaling techniques. While scaling and mapping, use a pocket tape recorder and camera for documentation. Identify potentially unstable hazard approaches, anchor types and their placement. Determine the best descent and ascent lines. Describe the general care of equipment and securing and climbing equipment to mappers.

Suggested equipment.—Use construction safety standard alpine and wire core manila lifelines and systems.

Documentation.—Establish ground control for mapping including terrestrial photo mapping. Data collected while scaling should be based on the purpose of mapping and detail required. Establish general map controls such as grid controls.

Special considerations.—Select specific portions of an exposure to be mapped.

Canal and Pipeline Mapping

General requirements.—In reconnaissance investigations, surface geologic mapping is of chief importance in determining the most feasible alignment, which may be representative of the geologic conditions to be encountered, the lining requirements, and construction materials evaluation. Design data, investigations along canal alignments must be detailed enough to support determination of the final alignment and all associated requirements for specifications and construction.

Preparation.—Safety considerations, planning.

Documentation.—Pertinent geologic data that should be shown on the base maps include: geologic units, all natural and man-made exposures, geologic structures, springs and seepage, surficial channels, potentially unstable explorations. Where appropriate, photographs with overlays or detailed site-specific drawings should be used to show surface conditions in relation to the canal prism or associated canal structures. Base maps should be plan strip topography or orthophotography with scales of 1 inch = 20 feet to 1 inch = 100 feet with associated topographic profiles.

Underground Geologic Mapping

Geologic mapping for tunnels, shafts and large chambers are to be performed using the outline below. The project and principal geologists must know the general requirements to complete their work for any of these excavations. They must be properly prepared, thoroughly trained, cognizant of the safety requirements and the construction schedules.

Tunnel Mapping—use either the developed surface method or the springline projection method. Figures 6-4 through 6-8 show preferred tunnel mapping methods. Large chambers can be mapped using the same criteria as used for tunnels. Shaft mapping usually is performed in the same manner, except that face sketches are not always required.

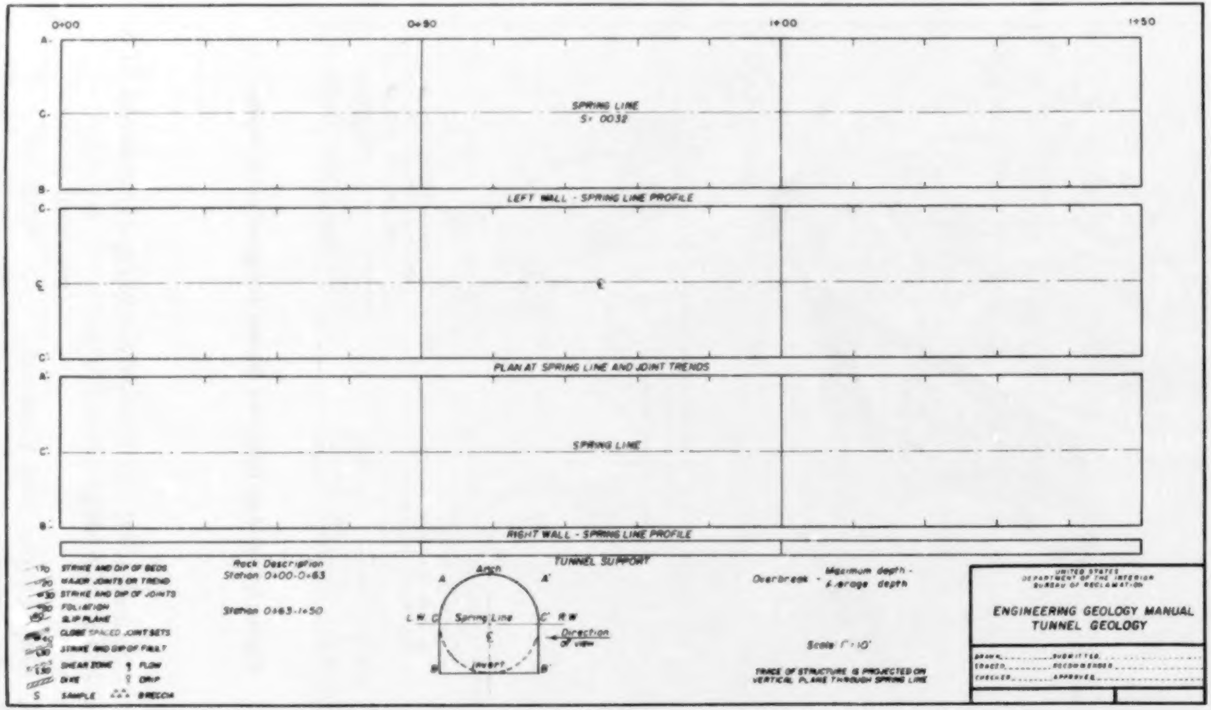


Figure 6-4.—Springline projection of tunnel geology.

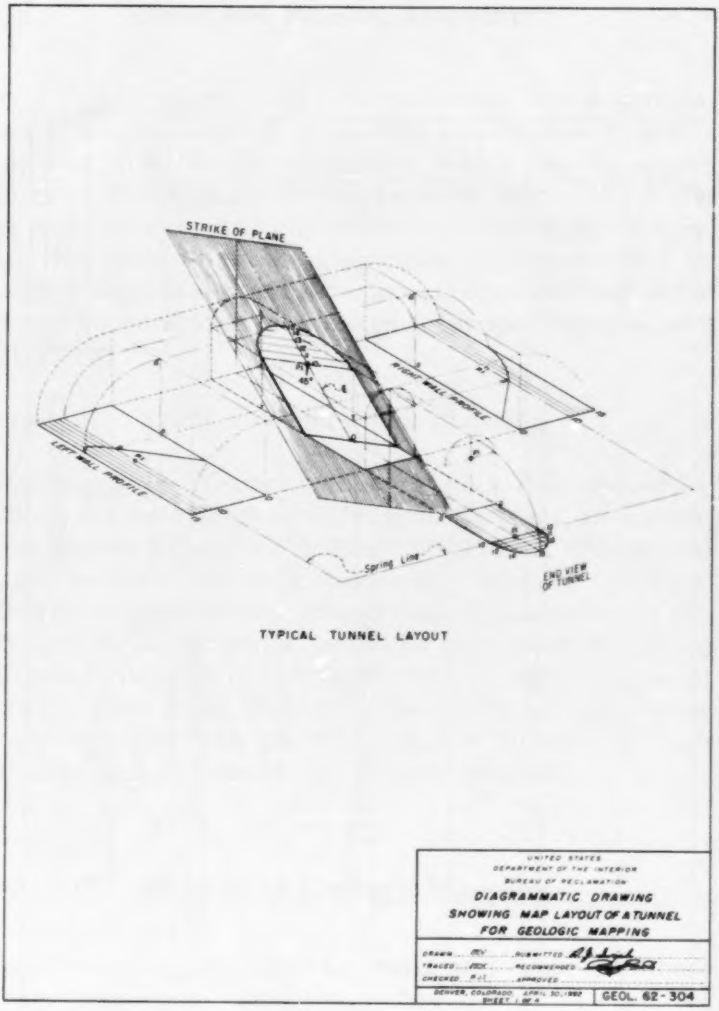


Figure 6-5.—Map layout of tunnel for geologic mapping.

The recommended outline for mapping excavations of tunnels, shafts, and large chamber is:

1. Map Layout and Control
2. Document:
   a. Lithologies
   b. Discontinuities

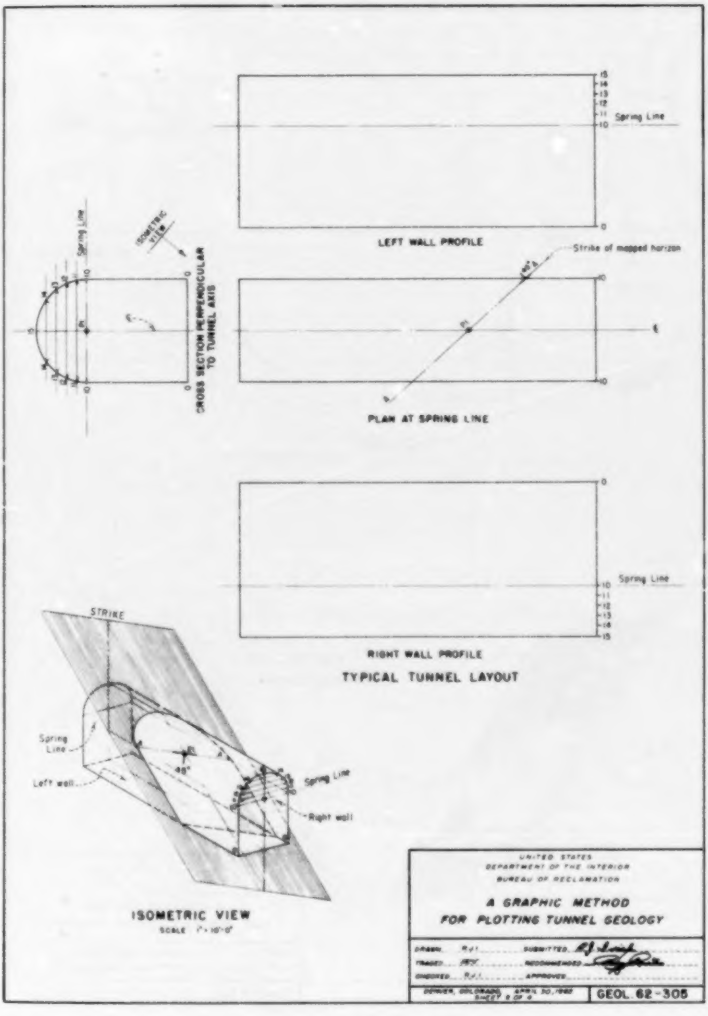


Figure 6-6.—Graphic method for plotting tunnel geology.

c. Water (location and quantity)
d. Supports (manufacturer and nomenclature—quantity & location)
e. Overbreak
f. Face Sketches
g. Notes & photographs (location)
h. Field Checks

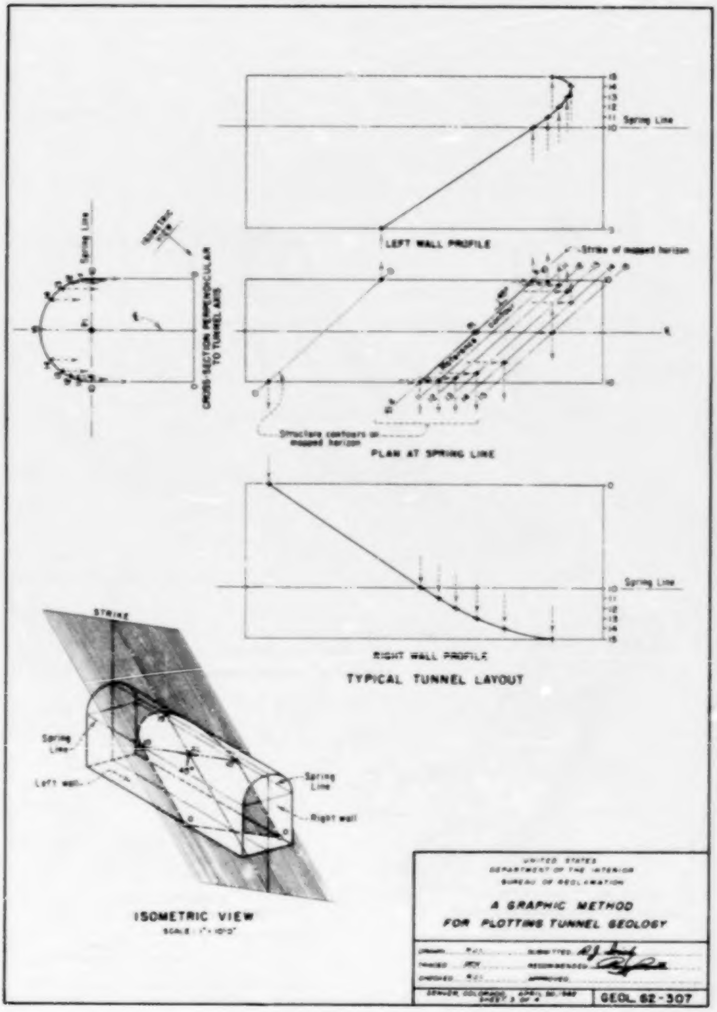


Figure 6-7.—Graphic method for plotting tunnel geology—spring-line projection.

Photogeologic Mapping

General

Aerial photographs generally are used in reconnaissance geologic mapping, geologic field mapping, and in generation of photo-interpretive geologic maps. Various scales of air-

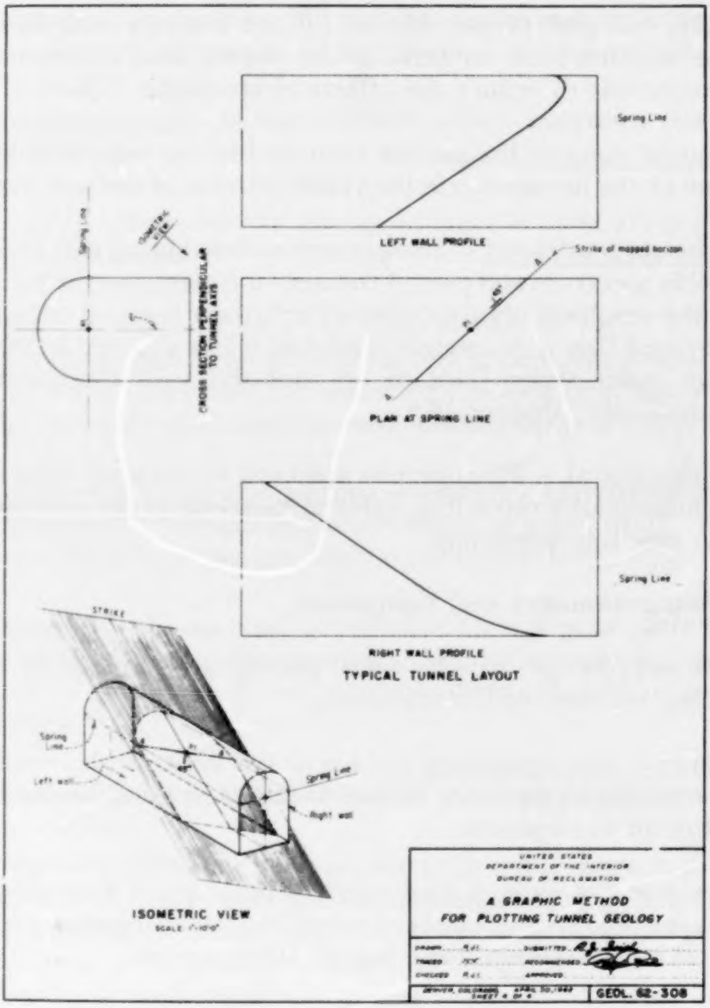


Figure 6-8.—Graphic method for plotting tunnel geology (sheet 2).

photos are valuable for regional studies and site studies, for both detection and mapping of a wide variety of geologic features of importance to engineering geology.

Types of Aerial Photographs

Panchromatic (black and white).—Panchromatic photography records images essentially across the entire visible spectrum, and with proper film and filters also can record into the near-infrared. In aerial photography, blue is generally filtered out to reduce the effects of atmospheric haze.

Natural color.—Images are recorded in the natural colors seen by the human eye in the visible portion of the spectrum.

False-color infrared.—Images are recorded using part of the visible spectrum and part of the near-infrared, but the colors in the resultant photographs are arbitrary and not natural. Infrared film is commonly used and is less affected by haze than other types. (Not to be confused with thermal infrared—see Chapter 16.)

Multispectral.—Photographs acquired by multiple cameras simultaneously recording different portions of the spectrum can ease interpretation.

Photogrammetry and Equipment

Use stereoscopes to view aerial photographs for maximum utility and ease of interpretation.

General photogrammetry.—Know the photo scale, resolution, and exaggeration. Be aware of the types of distortions inherent in airphotos.

Stereoscopic viewing equipment.—Basic aerial photograph viewing equipment can be divided into two categories—lens (pocket) stereoscopes and mirror stereoscopes.

Compilation of Photogeologic Map Data

Map on transparent overlays. Transfer photogeologic data to base maps. Take care to minimize effects of distortions in photos when transferring data to maps. Orthophoto quadrangles can help in this.

Analysis of Aerial Photographs

General Interpretive Factors

Analysis of aerial photographs involves interpreting indirect data. In most cases, several factors are used to interpret specific geologic conditions. Interpretive factors usually used in the analysis of aerial photographs are:

Sun angle.—High or low illumination angles may be desired, depending on the nature of the features to be detected.

Photographic tone.—Variations in color, intensity, shade and shadows.

Texture.—Frequency of change in tone, evident as roughness, smoothness.

Color.—True and false-color imagery may be easier to interpret than panchromatic photographs, depending on features being observed. For some applications (e.g. low sun angle photography) panchromatic photography is better.

Geomorphic shape and pattern.—Geologic conditions can be identified by mapping various types of geomorphic features related to drainage, bedding and structure.

Vegetation.—Some types of vegetation and vegetal patterns can assist in interpreting geology. Vegetation may indicate depth of soil, type of soil, available moisture, and type of bedrock.

Photoanalysis for Reconnaissance Geologic Mapping

Photo-reconnaissance geologic mapping can be done to produce a preliminary geologic map of the study area prior to going into the field to check and verify the interpreted geologic data, or to produce a finished geologic map with little or no field checking of the geologic data interpreted. For ease of discussion, the first type of map will be called a photo-reconnaissance geologic map, and the second type of map will be called a photo-interpretive geologic map.

Photo-Reconnaissance Geologic Mapping.—Photo analysis prior to field examination allows the mapper to form a preliminary concept of the geology of the study area and to select areas for detailed examination. Prior photo-analysis is critical if available field time is limited. It can be especially valuable when a large area is involved, as in regional studies, reservoir area mapping, and pipeline or canal alignment studies.

Photo-interpretive Geologic Map.—Geologic maps produced solely from aerial photographs with little or no field checking are useful when time, funds or access are limited or when adverse weather prevents a more detailed field mapping program. The limitations of this form of geologic map are dependent on outcrop density and degree of exposure, amount of vegetative cover, contrast of the geologic units and the skills of the photogeologic mapper.

Photoanalysis During Geologic Field Mapping

The location and verification of geologic features in the field can usually be expedited by using aerial photographs. Photographs can be used to clarify and speed up field mapping by allowing a comprehensive view of the study site and the relationships of the various geologic features exposed. Alternately viewing photos and examining outcrops can greatly facilitate mapping.

Availability of Imagery

Aerial photography is available, commonly in a variety of scales and types, for essentially the entire conterminous United States. The principal repository of publicly owned airphotos is the EROS Data Center, operated by the U.S. Geological Survey. Another major source is the ASCS (Agricultural Stabilization and Conservation Service) of the U.S. Department of Agriculture. The USGS also has several regional offices of the NCIC (National Cartographic Information Center). The NCIC operates the APSRS (Aerial Photography Summary Record System), which is a standard reference data base for users of aerial photographs. The APSRS lists aerial photography available from a large number of government agencies and commercial companies. The lists are comprehensive and are available on microfiche, categorized by state and by latitude and longitude. ASPRS microfiche is available on request from NCIC at no charge. NCIC also provides information about cartographic products other than imagery. These offices offer assistance to walk-in customers as well as by mail or telephone.

Some important addresses and telephone numbers are:

USGS FTS:784-7151 Comm:(605) 594-6151
EROS Data Center
Sioux Falls, SD 57198

USGS FTS:776-5829 Comm:(303)236-5829
NCIC, Stop 504
Denver Federal Center
Denver, CO 80225

USGS FTS:459-4309 Comm:(415)329-4309
NCIC
345 Middlefield Road
Menlo Park, CA 94025

USDA-ASCS
Aerial Photography Field Office
Customer Services
2222 West 2300 South
P.O. Box 30010
Salt Lake City, UT 84130-0010

The Remote Sensing Section, Code D-3744, Denver Office, can also assist in determining availability and in acquisition of airphotos.

Mission Planning

Successful airphoto mission planning requires consideration of several factors, including film type, scale, time of day (sun-angle), time of year, and the size of the area to be covered. Mission planning should not be done by someone unfamiliar with the process without assistance. Specifications should be written to insure that the resulting photographs will be satisfactory for their intended purpose. Information critical to mission planning is available from the references listed below, and technical assistance is available, also discussed below.

Time and Cost Estimating

The cost of data acquisition is relatively easy to estimate. The cost of interpretation is much harder to estimate, being a function of the time required, which is related to the size and complexity of the study area and the skill of the interpreter. The cost of a single drill hole will pay for a lot of aerial photography and interpretation.

Technical Assistance

The staff of the Remote Sensing Section, Code D-3744, Denver Office, is comprised of specialists in remote sensing. They can provide technical assistance in acquisition of existing airphotos, in mission planning if none are available, and in time and cost estimation. The Remote Sensing Section may also be able to assist the geologist is airphoto interpretation, or do the interpretation for the geologist. In general, however, it is best for the geologist working at the study area to be directly involved in photogeologic interpretation.

References

A classic text on the use of airphotos in geology was reprinted in 1985 and should be readily available. Though some of the equipment it describes is obsolete and it is essentially limited to discussion of panchromatic photography, it contains numerous stereopairs with geologic descriptions and remains one of the best works on airphoto interpretation for geologists:

Ray, R. G., Aerial photographs in geologic interpretation and mapping: U. S. Geological Survey Professional Paper 373, 230p., 1960.

Other useful references, with considerable overlap of material, are:

Lattman, L. H., and Ray, R. G., *Aerial photographs in field geology*, Holt, Rinehart and Winston, New York, NY 221p., 1965.

Miller, V. C., *Photogeology*, McGraw-Hill, New York, NY, 248p., 1961.

A reference containing no general discussion of principles, but with excellent examples of stereopairs of geologic features, associated topographic maps, and geologic annotations, is:

Scovel, J. L., et al., *Atlas of Landforms*, Wiley & Sons, New York, NY, 164p., 1965.

A broad and lengthy reference covering remote sensing in general, including much information about aerial photography of all types, is:

Colwell, R. N. ed., *Manual of remote sensing*, 2nd edition: American Society of Photogrammetry, Falls Church, VA, 272p., 1983.

BIBLIOGRAPHY

[1] Bates, Robert L., and Julia A. Jackson, editors, *The Glossary of Geology*, 3rd edition, American Geologic Institute (AGI), Alexandria VA, 1987.

[2] Lahee, Frederic H., *Field Geology*, 6th edition, McGraw-Hill, Inc., New York NY, 1961.

[3] Compton, Robert R., *Manual of Field Geology*, John Wiley and Sons, New York NY, 1962.

Chapter 7

DISCONTINUITIES SURVEY

General

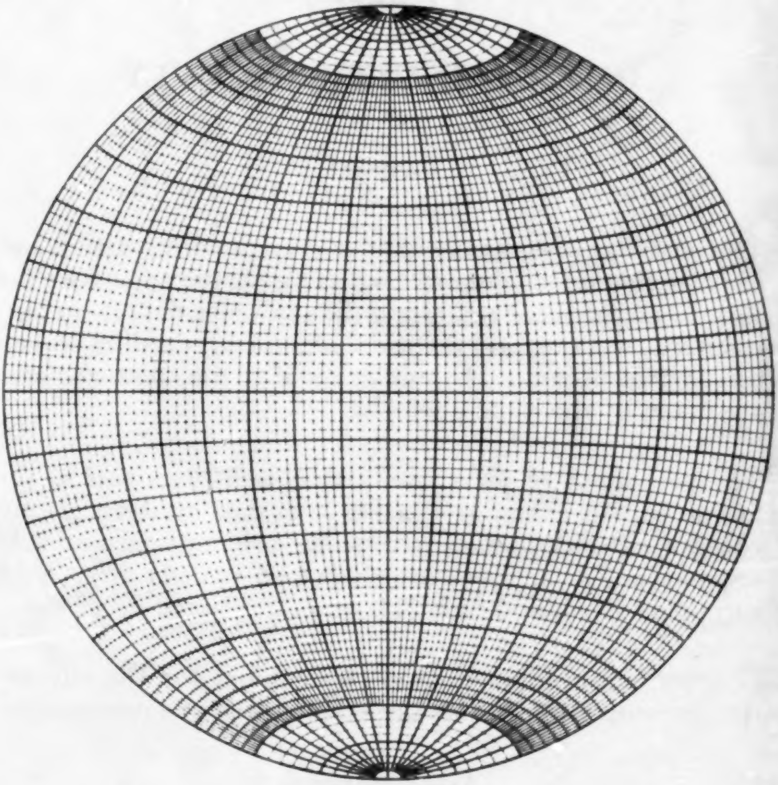
The importance of discontinuities in engineering design and construction is well documented. This chapter discusses the various methods for recording discontinuity data from outcrops, excavations, and vertical shafts. Bias recording of data is ever present but can be minimized if all the measurements are taken by the same geologist.

The evaluation of joint data also is well described in the literature. For example, plotting joint data on stereograms, contouring to determine prominent orientations, and subsequent wedge analyses are described in *Rock Slope Engineering* by Hoek and Bray [1].

Chapter 5, Terminology and Descriptions for Discontinuities, presents data that should be recorded in a joint survey.

Areal Mapping

Recording joint data is a standard and well known procedure for geologically mapping an area for a civil structure. The orientation of the discontinuity can be recorded either as a strike and dip or as a dip bearing and plunge. Whichever method is used, it must be used consistently throughout the survey. Exercise thoroughness in recording joint orientations—do not overlook the subtle joints (i.e. near horizontal) for the obvious and easily recorded joints. This element in joint surveys tends to reduce the mapper's bias in the collection process. Data must be recorded on a form for easy plotting on a Schmidt net (fig. 7-1) either manually or for entry in a computer program. Figure 7-2 is a polar equal area net that facilitates plotting poles from a survey that recorded orientation in the strike/dip form. Computer entry can be either by strike and dip or dip direction and plunge. Evaluating the plots requires an understanding of the method of entry and form of presentation.



SCHMIDT NET

Figure 7-1.—Equatorial equal area net (Schmidt Net).

Record the rock type for each orientation. Studies have shown different rock types in the same structural terrain have different fracture maxima. This may be an important factor for evaluating tunneling conditions, rock slopes, or estimating the in-situ stress field in underground openings. Also, spacing of joint sets may vary for individual rock types (i.e. different bed thicknesses).

The question arises, how many "points" are needed in a discontinuity survey to have confidence in the subsequent analysis? A fracture analysis (fig. 7-3) randomly removed joints from a 200 point survey to a 20 point survey. With 60 points remaining, the maxima did not change from the 200 point maxima. Hence, at least 60 joint orientations are

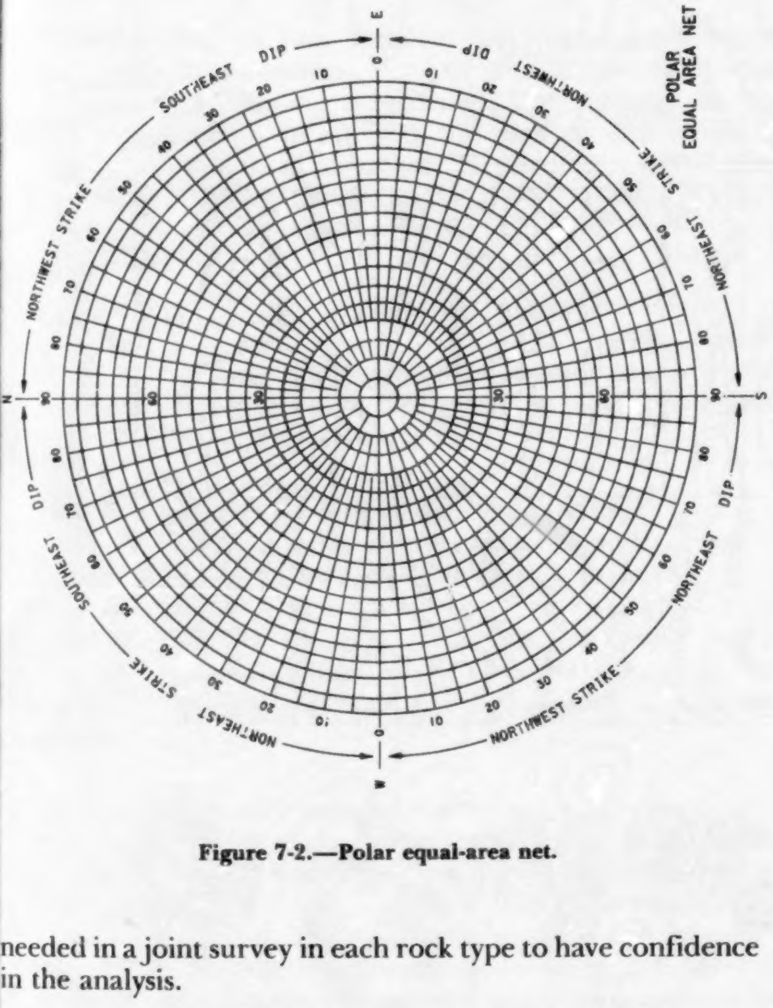


Figure 7-2.—Polar equal-area net.

needed in a joint survey in each rock type to have confidence in the analysis.

Detailed Line Mapping

Line mapping is a more recent development in collecting discontinuity data and can substitute for areal mapping techniques. Line mapping was made popular by Piteau [2] as a method of mapping road cuts and open pit excavations. This method had been expanded both in scope and types of exposures mapped. Limitations of the procedure to determine true discontinuity (set) spacing and trace lengths are addressed by Priest and Hudson [3] in which they propose methods of correcting the bias produced by line surveys. Some programs for analysis of data by computer permit

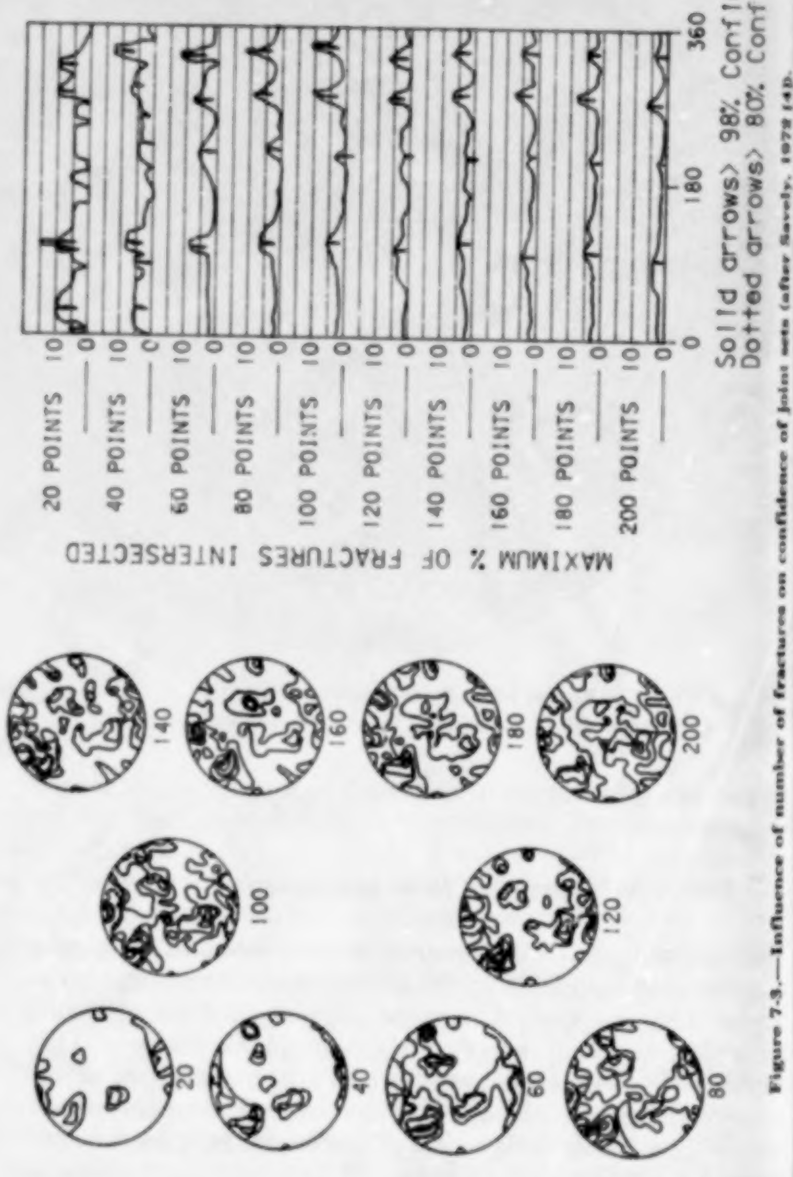


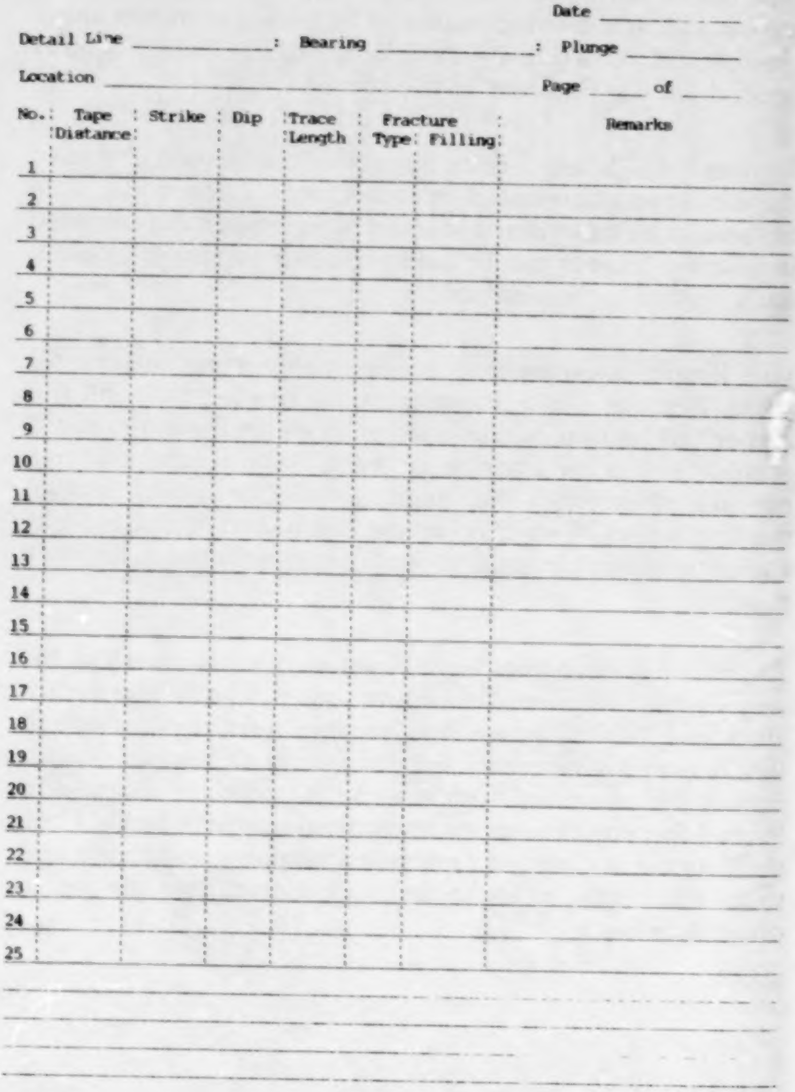
Figure 7-3.—Influence of number of fractures on confidence of joint sets (after Savely, 1972 [4]).

correction for line bias. Detailed line mapping involves establishing a linear traverse along which each geologic feature that intercepts the line is recorded. The traverse can be a tape placed across an outcrop, the rock rib of a tunnel, or a shaft wall at a fixed elevation. The geologist moves along the line and records everything as noted in Chapter 5 or as needed for the final use of the survey.

Figures 7-4, 7-5, and 7-6 are forms that can be used to record the data in an abbreviated or coded form. These coded data are similar to those descriptors for discontinuities presented in Chapter 5. Data can be entered into a computer or manually plotted for evaluation.

Line lengths must be long enough to intercept at least 60 joints. Because it is a linear traverse, looking "around the corner" of an outcrop, as is done in an areal survey, is not possible unless the traverse is "bent" or a second traverse run to include joints that might parallel or closely parallel the first survey. Two line surveys conducted at nearly right angles is desirable and should be completed whenever possible.

Reclamation geologists have developed a new method for very detailed mapping procedure that will be field tested in 1989 and 1990. The method involves a fixed point or rail that provides a reference for very accurate measurements. Strikes are measured with a strike goniometer indexed to the rail thereby eliminating anomalous magnetic fields. Presently its use is directed to detailed mapping in tunnels and shafts and hence, its use to data collection during the design phase is limited.



Date ____________

Detail Line ____________: Bearing ____________: Plunge ____________

Location ______________________________ Page _____ of _____

No.	Tape Distance	Strike	Dip	Trace Length	Fracture		Remarks
					Type	Filling	
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							

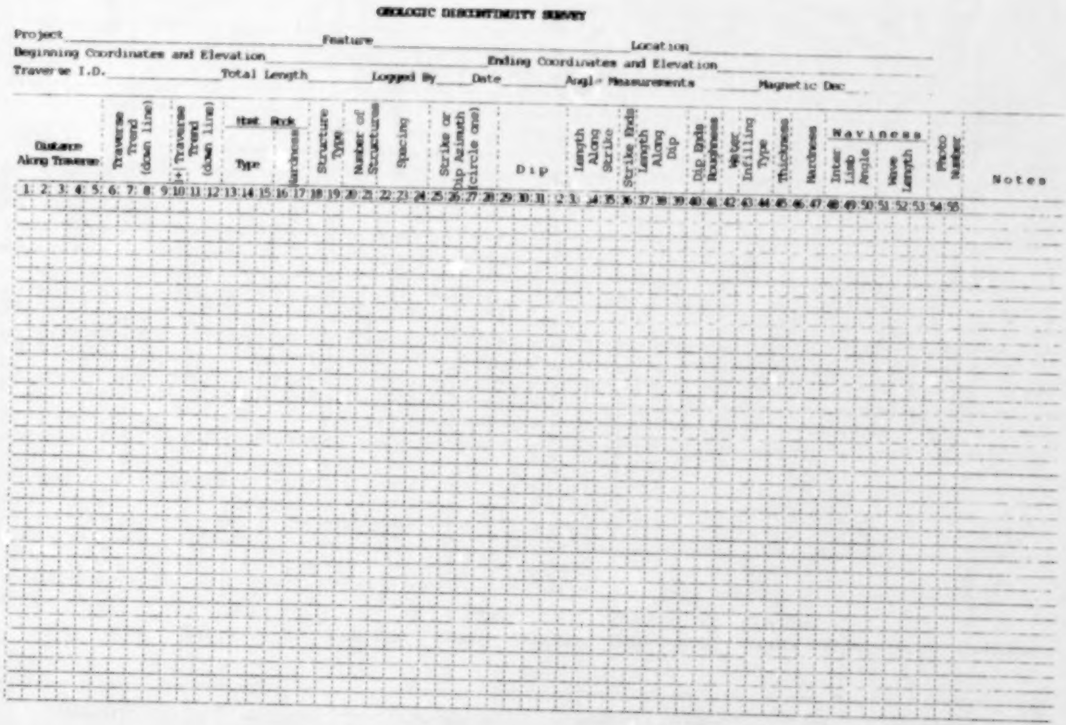
Figure 7-4.—Form used for detail line mapping.

SITE ______ LOCATION ______ SYSTEM ______ DATE ______ NAME ______

TRAVERSE	NORTHING	EASTING	ELEVATION	TREND	PLUNGE	REF	LENGTH	OBS.

DISTANCE	ROCK	HDN	STR	AZIMUTH	DIP	DIR	INFILLING	LENGTH	SPCG	E	W	R	GOUGE WIDTH	WAVES	N/S	COMMENTS

Figure 7-5.—Data record for detail line mapping.



GEOLOGIC DISCONTINUITY SURVEY

Project________ Feature________ Location________
Beginning Coordinates and Elevation________ Ending Coordinates and Elevation________
Traverse I.D.________ Total Length________ Logged By____ Date______ Angle Measurements ______ Magnetic Dec____

Distance Along Traverse	Traverse Trend (down line)	+ Traverse Trend (down line)	Host Rock		Structure Type	Number of Structures	Spacing	Strike or Dip Azimuth (circle one)	Dip	Length Along Strike	Strike Ends	Length Along Dip	Dip Ends	Roughness	Water	Infilling Type	Thickness	Hardness	Waviness		Photo Number	Notes
			Type	Hardness															Inter Limb Angle	Wave Length		
1 2 3 4 5	6 7 8 9	10 11 12	13 14 15	16 17	18 19	20 21	22 23 24	25 26 27 28	29 30 31	32 33 34 35	36	37 38 39	40	41	42	43 44	45	46 47	48 49 50	51 52 53	54 55	

Figure 7-6.—Data record for detail line map.

Bibliography

[1] Hoek, E., and Bray, J., *Rock Slope Engineering,* Revised 3rd edition, The Institute of Mining, London, 1981.

[2] Piteau, D., Geological Factors significant to the stability of the slopes cut in rock. Proceedings of the Open Pit Mining Symposium S. African Inst. Min. Metall., Sept., 1970.

[3] Priest, S. D., and Hudson, J. A., Estimation of Discontinuity Spacing and Trace Length Using Scanline, 1981.

[4] Savely, J., Orientation and Engineering Properties of Joints in Sierrita Pit, Arizona. MS Thesis, University of Arizona, 1972.

Chapter 8

CONSIDERATIONS FOR THE DEVELOPMENT OF AN EFFECTIVE AND EFFICIENT EXPLORATION DRILLING PROGRAM

Introduction

This chapter describes criteria recommended for use as a guideline in the development of an effective and efficient exploration drilling program. More often than not, drilling programs that involve extensive soil sampling, rock coring, instrumentation installations, or in situ testing end with excessive overruns on cost and completion time. The effort put into the development of a well organized drilling program that explicitly defines all drilling requirements can lower exploration costs significantly, eliminate unnecessary work, and generally can result in completion within established time schedules.

Preplanning the Exploration Drilling Program

The person responsible for the development of the exploration program should have a thorough knoweldge of the design concerns, soil or rock core testing, site conditions, and equipment requirements to accomplish all objectives. It is extremely important that exploration parameters be identified to avoid over-design of any program.

A complete and detailed description of the drill site location, accessibility, work requirements, known geology, and other pertinent information should be made available to either the drilling contractor or Reclamation drilling staffs. This information is valuable to ensure that an effective and efficient drilling operation will accomplish the program objectives.

The following paragraphs list information essential to organize and develop an effective and efficient exploration program, and provides methods that may be used to obtain the information.

Site Inspection

An on-site inpsection of the drilling location is to be made by the Principal Designer, Principal Geologist and other essential members of the exploration team. The purpose of the on-site inspection is to reach agreement on the generalized type of exploration required to provide the best data for design.

During the site inspection, the Principal Designer and Principal Geologist should discuss in detail all of the design concerns that can only be solved by analyzing the subsurface geology. They should be explicit as to the size, quantity, type, and quality of soil or rock samples that are necessary for testing to develop an accurate analysis of the geologic structure. The Principal Geologist can recommend the type of equipment and drilling procedures needed, which should be based upon the drilling requirements, and to address all design concerns as well as to meet the sample requirements for laboratory testing.

The on-site inspection will provide other pertinent information which is critical to the selection of specific equipment, and work procedures to follow. The following drilling concerns should be addressed when preparing the exploration plan.

Topography-Drill Site Accessibility.—Determine what type drilling equipment is most suitable to perform the work; consider truck-mounted, all-terrain, skid-mounted, or a combination of several types. Also consider the need for heavy excavation and hauling equipment to construct access roads, build drill pads, construct ravine crossings, construct temporary bridges or pipe culverts for river crossings. Determine the need for explosives and track drills to prepare drill pads or remove unsafe rock overhangs from drill sites, roadbase or rockfill to be placed over soft mud or marsh drill sited, helicopter support for fly-in rigs, heavy timber clearing. Other considerations are: is there a relatively close and level area to the drill sites that may be used as a temporary drill yard staging area, and how close can equipment hauling units be driven safely into the drill area.

Right-of-Way, Access Permits, Drilling Permits, Construction or Clearing Permits.—Consider the drilling locations i.e., whether on public or private land and if all access permits have been obtained and what are the limitations of the permits. Determine if construction or clearing permits are needed or have been obtained and what are their conditions. Most states require special licenses or permits for drill operators that perform water-well drilling and installation.

Protection of the Environment

Determine the disposal of the cleared material. The use of drilling mud offers some problems that should be solved prior to drilling. Therefore, consider if the drill mud circulation pits can be excavated, and if the mud pits have to be enclosed with chain-link fencing to keep out animals; also, how to dispose of drill mud and cuttings residue and how to dispose of fuel and oil spills or oil change residue. Determine if shallow streams can be forded without contamination. Thoroughly explain how the drill holes are to be completed in relation to eliminating animal hazards and what is required to restore the drill site to its natural condition? Dust abatement programs may have to be put into effect for travel over the access roads. If necessary, establish routes for travel through crop fields.

Drilling Concerns

These concerns must be addressed during the development of the exploration plan. Do the drill sites have rock outcrop? Can downhole hammers be used to set collar casing? Is the surficial deposit primarily clayey material whereby hollow-stem augers may be used? If the drill hole is to be water-pressure tested, may drilling mud or air foam be used? Are suficial deposit samples required? Can casing, or hollow-stem augers be avanced through the surficial deposits so that rock coring can be performed? Can the drill hole be used to combine geophysical and in situ testing? Will geophysics testing be required in the drill hole? Are angle holes required? Will the holes require directional drilling control and then be verified by survey? Will PVC casing have to be installed for survey confirmation? Will water-pressure tests or permeability tests be required as the hole is drilled, or can the testing be performed after the hole is completed? Will the permeability tests require packers and pressure testing or gravity head pressure? Will the holes require instrumentation installation? What are the requirements for the backfill in the instrumentation drill hole, and how is it to be placed? Will the outside annulus of the casing require grouting? Can a cement float shoe be used to grout the casing and make the grout exit into the casing annulus?

Equipment Concerns

Are the requirements for soil sample and/or rock core sizes compatible with existing commercially available equipment? Will the samples or cores have to be transmitted to the testing laboratories in sealed liners — split tube liners — thin-wall steel tubes — cheesecloth and wax seal within core boxes? Are there special concerns for the samples and their delivery? Will those concerns require them to be transported in vibration-free containers? Should the samples be weighed in the field and the density and moisture content determined before delivery to the laboratories? Considering the total hole depth, size of core or soil sample requirements, borehole diameter, and rod size, what is the minimum drill equipment rating that should be specified? What is the minimum mud pump or air compressor rating that should be specified? Where is the water source, will it have to be hauled or can it be pumped to the drill site? If not, how much water line will have to be laid?

Traffic Control and Safety Concerns

Consider the following: Will the drill locations require traffic control, detours, barricades, flag personnel, etc. for safety and public protection? Will road or highway travel require rerouting during the drilling program? Has permission been obtained from local, county or state officials to close roads?

Will drilling be performed in an area of high visual concentration? Will equipment security and vandalism potential be a problem significant enough to warrant the installation of security fencing around the drill site or arrange for night-time security personnel?

Special Considerations

Will the drilling involve specialized drilling procedures, i.e. concern for hydraulic fracturing of an embankment dam?

Will the drilling require ramps and drill pads to be excavated into the slope face of an earth embankment? Will the embankment slope face drilling have to be performed with skid-rigs on timber cribbing platforms, or with specialized drills that are capable of traversing and drilling into embankment slope faces without the need to excavate ramps or benches?

Will underground drilling be required? Establish and include all underground safety requirements in the drilling specifications? Size the underground drilling equipment so it will be suitable for the height and width of the tunnel or drift. Consider if there is potential to tap large volume water pockets, or to intersect reservoir seepage paths during underground drilling operations.

Will the drilling program require drill setups on scaffolds or hanging platforms? Are qualified personnel available to review the design of any scaffold or hanging platform drill setup, and will they have the authority to accept or reject the construction of same?

Will the drilling program require operation from a floating plant (barge) or a jack-up platform? Obtain data for fluctuating river rises or falls, flow rate, and depth of water under normal flow conditions.

Will drilling be required in the vicinity of overhead transmission lines, transformer boxes, or underground buried utilities? Have all underground utilities been located and flagged?

Will the program require helicopter service for fly-in rigs? Identify all fly-in hazards prior to start-such as transmission lines, heavy timber, turbulent winds, and rough terrain. Flight control by local air-traffic controllers may be required.

Are artesian pressures anticipated? Are circulation loss zones anticipated? Prepare contingency plans to seal and contain artesian water flow, or large volume water flow that may be encountered during any drilling operations. Prepare contingency plans for the potential changes or extensions to the exploration program.

Determine how the drill holes are to be completed, i.e., capped and locked collar casing, collar casing guard fixtures, or install piezometers or other monitoring instrumentation, or backfilled and grouted.

Preparation of Drilling Specifications and Format

Information obtained through a thorough understanding of the requirements should be compiled in a clear and concise manner for use by the pesonnel who will perform the work. The following is a suggested format to organize pertinent requirements into the specifications for drilling contracts.

a. General Description of Exploration Program

(1) Available Geologic Data

(2) Identification of Design Concerns

(3) Generalized Exploration Drilling, Coring, Testing, Instrumentation Requirements

b. Location of Work

(1) Area Identification

(2) Nearest Township

(3) Emergency Facilities

(4) Nearest Living Quarters/Crew Camp Area

(5) Freight Facilities

(6) Fuel and Supply Business Locations

(7) Travel Routes/Road Restrictions

(8) Public/Private Land Access Routes/Restrictions

(9) Right-of-Way—Permits

c. Site Location

(1) Hole Locations

(2) Topography—Accessibility

(3) Protection of the Environment

(4) Water Source

(5) Waste Disposal Area/Acceptable Waste Disposal Method

(6) Drill Yard Storage Area—Restrictions

d. Work Requirements

(1) Site Preparation

(2) Collaring Holes—Boring Size—Angle

(3) Casing Requirements

(4) Sample Definition (Disturbed/Undisturbed)

(5) Sample Sizes and Intervals

(6) Care and Transportation of Samples

(7) Core Sizes and Intervals

(8) Care and Preservation of Rock Core

(9) In Situ Testing Requirements

(10) Instrumentation Requirements

(11) Hole Backfill — Completion

(12) Site Cleanup

e. Equipment Requirements

(1) Drill Rig Capabilities

(2) Pump/Air Compressor Capabilities

(3) Drilling Media for Cutting Removal

(4) Sampling/Coring Equipment

(5) In Situ Testing Equipment

(6) Instrumentation Equipment

(7) Core Boxes/Sample Containers

f. Special Drilling Concerns

g. Potential for Program Change, Modification, or Extension

h. Safety Program/Safety Requirements/Safety Contingency Plans

i. Exploration Drilling Reports

j. Labor Checks/Equipment Checks/Cost Accounting

Chapter 9

GROUND-WATER DATA ACQUISITION METHODS

Introduction

This chapter provides the user with general background theory and data required to select, install, and operate appropriate ground-water instrumentation and to collect, establish, maintain, and present the ground-water data base. Most types of engineering geology investigations require acquisition and use of ground-water data. Data required may vary from simple monthly verification of the water-level elevation along a canal-axis profile to hourly monitoring of piezometric conditions in multiple zones within a landslide or embankment. Successful implementation of a ground-water instrumentation program is dependent upon knowledge of subsurface conditions, preliminary identification of all probable future uses of these data, and careful planning of an instrumentation system and data acquisition program to meet these data requirements. The scope of this chapter is limited but will provide the user with:

- A partial listing and discussion of more detailed and specific source material on ground-water investigation.
- A review discussion of theories of ground-water movement pertinent to design of instrumentation systems.
- A detailed description of methods employed in designing and installing ground-water monitoring wells.
- A detailed description of available manual and automated methods and techniques used in monitoring ground- and surface-water.
- A discussion of data base management and data presentation.

Background Data Review of Theories and Terminology

Occurrence of Ground Water

This section provides some of the factors and considerations that influence the design of ground-water data acquisition systems; and is offered as a review of basic concepts that are tools to be considered to insure maximization of data obtained from the field exploration. A listing of key definitions is appended for use and reference.

The importance of fully evaluating and understanding geologic factors controlling ground-water flow—including porosity, storativity, permeability, transmissivity, velocity, recharge and discharge—cannot be over-emphasized. This evaluation needs to be made at the onset of the exploration program and continually re-evaluated and adapted for throughout the investigations. These factors will ultimately control the type of ground-water instrumentation required.

Geologic Controls on Ground Water

Geologic controls on ground-water flow impact the design of observation and must be identified in the preliminary planning of the instrumentation program. For example:

1. Permeable materials, such as clastic sediments, karstic terrain, and fractured rock, control the type and size of well point or well screen to be used and must be accounted for in designing instrumentation for the program.

2. Relatively impermeable materials, such as clays, silts, shales, siltstones, and massive rock present special problems which must be accounted for in selection of the type and size of piezometer to be installed. Generally these materials require use of the smallest size (I.D.) piezometer practical as changes in water level are small and require long periods of time to reach a meaningful level. Consideration should be given to utilizing pore-pressure measurements in this type of geologic environment, particularly if data needs are for documentation of periodic—daily or weekly—changes in ground-water conditions.

3. Layering, attitude of layers, boundaries, weathering and alteration, and environment of deposition all influence site selection for observation wells.

Design and Installation of Monitoring Wells or Piezometers

Design and Installation

The type of structure and the effects of ground-water on the design, construction, operation, and maintenance of the structure are the first considerations. The geologists knowledge of the geotechnical environment at the site, based on preliminary research and feasibility reports, are essential. Another essential and often missed point at this phase of the investigation, is the effects of the proposed construction on the natural environment at the site. Will the structure impede or impace ground-water movement through the area? Will the structure afford an entry point for contaminants into the aquifer? Will the structure impact natural slope stability within the construction site, or up- or downstream of the site? How can the long term need for ground-water data be incorporated into the scheme of foundation design investigations? Preliminary consideration of factors such as these will help avoid costly delays in construction schedules, redrilling for the sole purpose of ground-water data collection needs, and will help analyze and anticipate potential construction claims.

Analysis of the Geologic Environment

The presence of variations in the geotechnical environment must be anticipated. Perched water tables, artesian aquifers, sources of recharge and discharge, known boundaries and barriers, and structural controls such as fractures, joints, faults, shears, slides, folds and stratigraphic contacts all play a role in selection of instrument types and sizes. The preliminary instrumentation design should be advanced enough to allow procurement of needed material, but flexible enough to adapt to changes dictated by changes in the environment.

Several types of ground-water observation wells meet the need for different data types. Observation well types are selected in accordance with the data type required and the type of aquifer material anticipated. To be useful, reliable, and accurate, the well design must be tailored to the subsurface conditions at the well. Single or unconfined aquifer zones can be monitored by using a screened or perforated stand pipe, or by burial in-place or a pore-pressure transducer. Multiple zones may be monitored using multiple drill holes, multiple piezometer standpipes in a single drill hole, or multiple piezometer ports in a single standpipe (Westby/Sinco installation).

Construction Materials

Construction materials for well monitors are dictated by the projected use of the observation well and the permeability of the aquifer. The diameter of the standpipe, the type of stand pipe used (metal vs plastic), screen slot size and gravel pack material are all variables dictated by aquifer characteristics. Example considerations follow:

1. In a relatively permeable material, the diameter for a standpipe is not critical; sand or gravel pack around the piezometer tip may not be required, but the screen slot size—piezometer ports—may be critical to the success of the installation. Inadequate screen slot size may render these data useless as water is moving through the aquifer. Erroneous data may be worse than useless; it may mislead the technical personnel who are evaluating these data to minimize the quantity of water the aquifer may yield.

2. In a relatively impermeable material, stand pipe diameter may be critical, a pack material of select sand or fabric wrap usually is required, and a well point or screen assembly usually is required, (0.010–0.020-inch [0.025–0.05 cm] slot size). Generally, the smallest diameter standpipe practical should be used in this sort of monitoring application, keeping in mind that the standpipe diameter must be consistent with methods of observation (minimal size if the standpipe is to be automated by installation of a pore-pressure transducer is 3/4-inch [1.9 cm]).

3. Installation of an Observation Well
a. A variety of material can be used to install the standpipe. PVC plastic pipe is economical and easy to install in fairly shallow (less than 100-foot [30 m]) drill holes. It is also fairly fragile, deformable, and easy to destroy ac-

cidentally during installation. Metal pipe is more durable, but generally costs more than plastic. Generally, black pipe is preferred to galvanized pipe as the zinc in galvanized pipe can react with the concrete in the isolation plug and destroy the seal. It also reacts with water and often generates piezo-electricity which then yields unreliable data. The I.D. (inside diameter) of the pipe is dependent on the permeability of the aquifer material and can vary from as small as 1/2-inch (13 mm) to 2-inch (50 mm) or larger. Diameter selection for the riser can be critical to future automation of the observation well. Generally, 3/4-inch (19 mm) pipe is the smallest practical size that can be used in automated applications. The minimum size is critical; variations in nominal I.D. can render a standpipe useless for automation. Reaming of the pipe prior to installation to remove burrs, weld seams, and blebs of galvanizing material is a necessary precaution to ensure that the standpipe will be usable in an automated mode.

b. Screen assembly selected can be one of the following: well point; well screen; perforated pipe (manufactured or "homemade"). Screen should be PVC or corrosion-resistant metal. Slot-size is determined by filter material size and aquifer material.

c. Gravel-pack material selected is determined by the particle size of the aquifer material which must be determined through a mechanical analysis. Reasonably well-graded sand, graded "pea gravel", or a fiber wrap can be used.

d. Plug material used to isolate the interval to be monitored can be cement grout, bentonite pellets, or a combination of the two. A bentonite slurry also may be used in some instances.

Design and Installation Techniques of a Ground-Water Monitoring Well

The most important facet in the design of a ground-water monitoring well is the understanding of the purpose and use of the well; whether for taking water samples or for measuring piezometric levels, for instrumentation, or for geophysical investigations.

The hydrogeologic environment and the type of investigative down-hole instruments that may be used in the well will influence the choice of well diameter, the casing type and screen to be used, and the interval to be monitored.

Components of a typical well include a screened interval surrounded by filter/gravel-pack material and isolated by a bentonite and/or cement grout seal, blank casing to the surface, and a protective well cover.

PVC is the most widely used material for standpipes (casing and screens) in monitoring wells. It is relatively inexpensive and presents few chemical interferences in water quality sampling. Many other materials are available for specific uses, including galvanized and stainless steel, Teflon, and other plastics.

The diameter of the well depends on the instrumentation and the intended use. If the well is to be sampled, by either pump or bailer, a 4-inch (100 mm) diameter hole is the minimum acceptable size for accuracy and for complete development of the hole. Wells used for measuring water level only may be smaller diameter or may have multiple small diameter standpipes within a 4-inch (100 mm) to 8-inch (200 mm) diameter hole. A standpipe designed to accommodate an M-scope water level sensor need only a 3/4-inch (19 mm) diameter. However, if the standpipe is to be instrumented with a pneumatic or vibrating wire piezometer, or if a recorder and electric probe will be used to monitor the water level, then the diameter of the standpipe depends on the size of the instrument to be installed. Lengths of well screen and casing (PVC perforated and solid standpipes) must have uniform inner and outer casing diameters. Inconsistent inner diameters result in problems when downhole instruments with little clearance are lowered into the well. If galvanized steel pipe is used, it may be necessary to ream the pipe to remove the beads and burrs resulting from galvanizing.

A filter pack is generally composed of washed sands and gravels, and is placed within the screened interval and may extend above the screen another 5 to 10 feet (1.5 to 3 m). The pack is designed primarily to allow water efficiently to enter the standpipe and prevent the entrance of fine silts and clay into the pipes through the slots. If the well is to be used for sampling, the pack material should be sterilized to prevent possible contamination before placement into the well. Tremie the gravel pack through a tremie pipe to prevent bridging. The top of the pack may be checked using a small diameter tamping tool, or a properly weighted surveyors chain.

A seal is installed to create and isolate an impermeable boundary between the standpipe and casing or drill-hole wall. The seal should be placed in a formation of low permeability such as a clay bed above the isolated aquifer to be monitored. This ensure that water will not travel vertically through the formation or around the seal.

Cement grout is susceptible to shrinkage due to temperature changes during curing and may crack. This causes a poor bond between the grout and the standpipe. Use a one-foot (0.3 m) bentonite seal. Place bentonite either by tremieing pellets or as a slurry, immediately below and above the cement grout seal. This helps ensure a reliable plug. Irrespective of the material, it must be tremied into place. This prevents bridging or caking along the hole wall. It is extremely important that the seal be reliable and the screened interval is monitoring only the desired formation.

In a drill hole containing multiple standpipes with each monitoring a distinct water bearing strata, there may be several isolating grout seals. To test the integrity of the seals, a gravity head test may be performed in which water is added to the shallowest standpipe and continuous water level measurements to detect any leakage through or around the seal are taken in the next lower standpipe. If the water leaks into the lower interval, the piezometric head will rise in the lower standpipe.

A protective cover helps to prevent damage to the standpipes and reduces surface-water drainage into the backfilled hole. The casing should extend 5- to 10-feet (1.5 to 3 m) below ground and be grouted into place. Upon completion of the monitoring well, each standpipe is to be blown dry and the water level allowed to recover to its static level. A completion schedule derived from the drillers' records and measurements should include the actual depths and thicknesses of each component of the well; the standpipe's total depth, screened interval, isolated interval, the type of filter pack, the depth and thickness of the isolating seals, and a reference point from which all measurements were taken such as top of casing of ground surface. Many excellent references are available to design and install ground-water monitoring wells for various purposes. Refer to these at the end of this chapter for more detailed instructions.

Methods Used to Monitor Surface and Subsurface Waters

Methods and Techniques Used to Monitor Observation Wells

Ground-water measuring data and instruments used are only as good as the individual gathering those data. A conscientious professional, whether a hydrotechnician, physical science technician, engineering technician, geologist, or engineer, must take time to understand the equipment and be able to gather field data from the instrument, thereby knowing these data are correct and exact.

Manual Methods Used to Monitor the Observation Wells

Chalk and surveyors' chain procedure.—Probably the oldest and one of the most reliable methods for measuring shallow wells is the surveyors' chain and chalk method. This method is not recommended where water-level depths exceed 100 feet (30 m).

A lead weight is attached to a steel measuring tape (surveyors' chain). The lower 5 feet (1.5 m) of the tape is wiped dry and covered with carpenter's chalk. The tape is lowered into the well and one of the foot marks is held exactly at the top of the casing. The tape is pulled up. The wetted line can be read to a hundredth of a foot (0.003m) on the chalked section. This reading is subtracted from the foot mark held at the measuring point, the difference is the depth to the water level.

Disadvantages to this method are that the approximate water depth must be known so that a portion of the chalked section will be submerged each time to produce a wetted line. When depths are greater than 100 feet (30m) the tape becomes difficult to handle.

M-Scope (electric tape) procedure.—Many companies in the water well measuring trade have manufactured an electric sampler or electrical depth gage. Soil Test, Sinco, and Johnson have developed an electrode suspended by a pair of insulated wires and an ammeter or buser that indicates a closed circuit and flow of current when the electrode touches the water surface. Usually, AA flashlight batteries supply the current. The insulated wire usually is marked off in 1-foot to 5-foot (0.3 to 1.5 m) intervals. It is best to use a device that has the measuring marks embedded directly into the line. Markers that are attached to the line slip too often, and too much, making it necessary to calibrate the instrument each time it is taken into the field.

With the reel and indicator wire in one hand and the index finger palm up over the casing or piezometer pipe, the wire is lowered slowly over the finger into the piezometer pipe or well casing. By sliding the wire over the finger the wire is not cut or damaged by the sharp casing or piezometer pipe. A series of readings are to be taken to eliminate any errors from kinks or bends in the wire. The water-level depth can be measured from top of casing using the markings on the insulated wire and a tape measure marked in tenths and hundredths of a foot. The advantage of this method is that for wells in which water-level depths are several hundred feet, they can be measured fairly quickly and accurately. The disadvantages to this method is that malfunctioning or mechanical problems develop in the instrument giving erroneous water-level readings. Before going into the field, the instrument must be checked for low batteries, tears, scrapes in the insulated wires, and iron-calcium buildup on the part of the electrode touching the water surface.

Airline and gauge procedure.—This method consists of a small diameter pipe or tube that extends from a point on top of the well casing of piezometer pipes to a length sufficient to extend several feet below the lowest anticipated water level. The exact length of airline must be measured as it is placed in the well. The airline must be air tight and is to be checked thoroughly in the office before taking it to the field. The airline must hang vertically and be free from twists and spirals inside the casing.

Quarter-inch (6.3 mm) copper or brass tubing can be used. The upper end of the airline is filtered with suitable connections and valve so that an ordinary tire pump can be used to pump air into the tube. A tie is placed in the line so that air pressure can be measured on a pressure gauge.

This device works on the principle that the air pressure required to push all the water out of a submerged portion of the tube equals the water pressure of a column of water of that height. One must know a reference point (e.g. top of casing or piezometer pipe), and the lower end of the airline. Air is pumped into the airline until the pressure on the gauge increases to its maximum point. Now all the water has been forced out of the airline. At this point, the air pressure in the tube just balances the water pressure and the gauge reading shows the pressure necessary to support a column of water of a height equal to distance from water level in well to the bottom of the tube.

If the gauge reads the direct head of water, it reads directly the submerged length of airline in feet. The total length of airline minus the submerged length gives the depth to water below the measuring point. If the gauge reads in pounds per square inch, multiply the reading by 2.31 to convert to feet of water. Care must be taken to have an accurate, calibrated gauge and a straight, air-tight airline.

Pressure gauge for monitoring artesian wells.—It is important to discuss how to measure artesian wells. Theoretically, for an artesian well, additional pipe or casing can be extended that will eventually equal the head of the rising water. A simple method to determine the artesian head is to attach a suitable gauge to the casing or the piezometer pipe. The gauge selected may be read directly in pounds per square inch or direct pressure in feet of water. Install a tee coupling on the piezometer pipe or on the casing so that a pressure gauge and valve can be attached to the tee. The valve may be used to bleed the pressure gauge to see if the gauge is working and can be used to measure the flow on the artesian well. It is highly recommended that when a pressure reading is observed, a flow measurement also be determined. The pressure gauge should be read and correlated at least once a month. During the winter months the valve should be regulated to allow the well to flow slightly to prevent the riser pipe from freezing and breaking. If the pressure gauge used is in pounds per square inch, multiply the gauge reading by 2.31 to obtain the head of water above the valve curtailing the flow of water.

Continuous Recorders

Stevens Recorder.—Stevens Recorder probably is the most reliable and economical way to record continuous water-level data. It is a float-type recorder produced by Stevens Water Resources Products. It consists of a 3- to 6-inch (76 to 152 mm) float connected to a pulley which turns a precalibrated gear drum. A power source such as a spring clock or small motor gives a constant indication of elapsed time.

Gears inserted between the float pulley and the chart drum provide a varied ratio of water movement on the chart. A time scale is available on the chart and continuous recordings may be maintained for several days up to several months. When a float recorder is used, a minimum size of a 4-inch (100 cm) well casing must be installed. Johnson-Keck has a water-level sensing instrument that can continuously record water levels in 1/2-inch (13 mm) pipe and larger. Thus, multiple piezometers in one well can be used to measure numerous water level zones. Transistorized circuitry to operate a battery powered motorized reel is used. The sensing bob is attached to one end of the control wire, and the other end of the wire is connected to the reel. The instrument is connected to a Stevens type F or Stevens type A recorder. The control wire is lodged around the recorder pulley, and the sensing device is placed in the casing. The sensing device seeks the water surface and once the water surface is found, the circuitry keeps the sensing device at the water surface.

Many float recorders can be attached to digital recorders for continuous records. Data from this type of instrument can be used and easily interfaced with a computer system.

Another advantage of the Stevens recorder is its versatility where hydrographs can be created with scales of 1:1 to 1:20 feet. The time element of the recorder is versatile. Most recorders can be set from 4 hours to several months. Therefore, significant amounts of data can be collected on a small piece of chart paper.

A good maintenance program is to be established by the Project Geologist and his staff. The instruments and data collected are only as good as the preventive maintenance. A routine, preventive maintenance program is to be scheduled for all the instruments. In some cases daily inspection of recorders is required; however, if the instrument is working properly, weekly inspections may be sufficient.

Bristol recorders.—Recorders for monitoring continuous artesian pressure conditions are produced also by Bristol Instrument Systems. Their system works similar to a Stevens recorder in that pressure and time are recorded on a chart. Usually, the instrument contains diaphragms that can be adjusted to varying pressure conditions. The spring-driven clock usually is calibrated for 30 days. The instrument is very useful for observing pressure changes in artesian wells, but is limited to spring, summer, and fall seasons in northern climates. A pressure gauge installed in the line between the casing or piezometer pipe housing the artesian water and the pressure recorder is very useful. This gauge provides a good indication of the working condition of the instrument.

Gas bubbler transducer.—Pneumatic or gas bubble transducers are manufactured by many companies and vary from a single readout box to a complicated array of instruments that will measure several observation wells at once. The basic theory is that gases are forced down a tube at a constant rate where the air is pumped past the diaphragm to where the pressure of the diaphragm and the water pressure are equal, a constant reading is obtained. This reading equals the amount of water over the diaphragm. This number multiplied by 2.31 will give the amount of head of water over the instrument. These instruments, as mentioned above, may be used as a single unit or connected into an electronic data acquisition system. Problems associated with pore pressure piezometers include clogging of the tubes or corrosion of the transducers.

Methods and Techniques Used to Estimate Flows from Seeps, Springs, and Other Small Surface Drainages

This section provides the user an accurate means to estimate flows from seeps, springs, and other small surface drainages. A more thorough and detailed discussion of weirs, flumes, stilling wells, and other techniques is offered in the *Water Measurement Manual* [1]. The engineering geologists often will encounter small seeps, springs, and intermittent drainages in their field investigations. These features can become key problems during design and construction. They also may be key indicators of environmental impacts that may be attributed to the project feature. It is important to note the location of drainage features, the rate of flow, and the time of year of the observation. Flow can be estimated accurately using the methods described below:

> Estimate the rate of flow (cubic feet per second) in an open channel using $Q=VA$, where:
>
> Q = rate of flow in ft^3/sec (cubic feet per second),
> V = velocity in feet per second, and
> A = cross sectional area of channel.
>
> The cross-sectional area is determined by direct measurements, where possible. Where impractical, the cross-sectional area may be estimated or scaled from a topographic map.
>
> Velocity is determined using a float, a measuring tape, and a stop watch. Time how long it takes a floating object to travel a given distance. This provides a crude, but reasonably accurate estimate of flow. Other methods may include a pilot tube or flow meter, neither of which a field geologist is likely to have when the initial observation is made.
>
> Substitute the values obtained into $Q=VA$ equation to obtain the rate of flow in cubic feet per second. Convert, and report the flow in gallons per minute, [multiply the flow rate obtained (ft^3/sec) by 448.3 (e.g., $0.2\ ft^3/sec \times 448.3 = 89.66$ gpm)].
>
> Measure flow from small springs and seeps directly by diverting the flow, or in some manner channel the flow

to a collection point and collect it in a container such as a pint jar or bucket. Determine the rate of flow by timing how long it takes to fill the container. Select points along a drainage where abrupt drop-offs occur and use this method. A geologists' pick can be used to dig a diversion channel for a collection point. It is better to measure however crudely, but if not possible, guess the flowrate at a minimum. Many more sophisticated methods can be used to obtain more reliable flow measurements, if necessary. Determination of the most appropriate method can be made if the preliminary data are available for use.

Computer-Based Monitoring Systems

General

For the monitoring of water levels in landslides in remote areas, it may be advantageous to automate the monitoring system. Monitoring landslides can require a great number of points, and frequent readings. In some cases, a variety of data types maybe required, which may include measurements for pore-pressure changes, as well as deformation and movement data. Systematic monitoring systems manufactured today are both feasible and desirable. Specific software required to collect, store, format, and present these data is available either currently or is being prepared and it will allow real-time analysis for a wide variety of data types. Much of this software is being developed to run on the Reclamation's VAX system.

Components of a Computer-Based Monitoring System

1. Instruments such as inclinometers, pore-pressure transducer, strain gauges, river or lake level gauges, and flowmeters are some of the components of a computer-based monitoring system. Electronic instruments are available in many sizes and shapes. If the system is to be automated, preliminary selection of the instrument type to be used must be selected during the initial design of the well. The smallest diameter electric piezometer commercially available is 1/2-inch (13 mm) O.D. The inside diameter of the riser pipe used in the well must be sized accordingly; 3/4-inch (19 mm) diameter pipe is commonly used. Riser pipe used for automated systems

should be reamed prior to installation to insure that all obstructions are removed.

2. Acquired data must be sent from the instrument string at the well to the central computer. This is done by one of several technologies including hardwire from the instrument to the scanner, radio telemetry, or phone lines. Most instrument signals are low voltage, and hardwire cabling is limited to the distance that data can be sent. If the distance to the central computer is great, supplemental measures must be taken. As an example, the Grand Coulee Project's Riverbank Stabilization Monitoring System is 8 miles (12.9 km) from the wells to the central computer.

Data from the monitoring points must be preprocessed in the field prior to transmittal to the central computer. A number of microprocessor data scanners that collect and reduce data have been installed at various field locations. The central computer querries the field scanners to obtain periodic field data via phone lines. The remote scanners can be integrated as frequently as desired by the technical staff. This may include a continuous data scan mode.

3. Data scanners, consisting of microprocessors, are required to reduce the instrument output to usable data. Data scanners can be the end destination for more simple systems data or they may be interfaced to a more elaborate system such as those at Grand Coulee. Generally, two types of signals are generated by the instruments using the geotechnical monitoring: (a) frequencies from vibrating wire instruments, and (b) voltages from semiconductor stain gauge instruments and inclinometers. Data scanners have been developed which accept and reduce data from both types of instruments and are available commercially.

4. Many different types of central computers are available. Software is available for use on the Reclamation's VAX system. Many instrumentation manufacturers offer complete packages of automate instrumentation systems including computer hard- and soft-ware. If the initial ob-

servation well system is designed for automation most of these systems will provide the high quality of data required.

Available Sources of Information

Available sources of information for some automated monitoring systems, software and installation techniques are:

- Grand Coulee Project Office—Stabilization Program
- Pacific Northwest Regional Office—Hydronet System

Special Applications

Instrumentation has been developed by Westby Instruments of Vancouver, British Columbia, and is marketed by Slope Indicator Company, Seattle, Washington. They allow multiple types of instrumentation to be used in a single drill hole. This system provides a multiple use casing to collect ground-water data from a large number of horizons within a single drill hole. Two types of casing are available. One is specifically for ground-water, more specifically pore-pressure observations; the other incorporates grooves in the casing so that the well can be completed for both ground-water and inclinometer observation. The casing is relatively easy to install. Isolation between horizons can be accomplished either by installing a bentonite seal or using a packer assembly designed as an integral part of the system. The system requires the use of pneumatic or electric read-out devices manufactured by Westby. Use of this system greatly reduces drilling costs, provides detailed monitoring of critical drill holes, and provides a greater flexibility than systems previously available. Small diameter drill holes can be used to obtain a large number of isolated piezometer intervals. Depending on the application, this installation can be very cost-effective. However, the system does not lend itself to automation very readily. Information on this system is available from Slope Indicator Company, Seattle, Washington.

Data-Base Management and Data Presentation

Standard forms are available to record field data. Often times standard data sheets must be modified for particular applications. Data sheets must include information that identifies the monitoring well number, location, elevation reference points, type and size of well, dates and time the well has been read, depth to water, elevation of water surface, and remarks as a minimum. Periodic readings of these observation wells over long periods of time generates numerous data sheets. Computerization of the data base can become a necessity very rapidly if data are to be readily usable. Software has been developed that is "user friendly" and makes development and management of the data base a routine and reasonably simple operation. Much of this software has been written to use the capabilities of the Reclamation's VAX system and is readily available to user's throughout the Reclamation for a nominal license fee. The sources cited in previous paragraphs are available, along with others, to assist setting up or providing information on available software.

Data base computerization allows electronic transfer of data to concerned parties, and greater flexibility in developing and formating data presentations. Data may be tabulated or presented as time-series plots such as river hydrographs, and interpretive drawings such as contours and other three dimensional plots. The computer will plot hole locations and elevations or will actually draw the geologic interpretations, depending on the need and imagination of the user. Tremendous volumes of data can be reduced quickly to a usable format. Software is readily available, for all of these applications. Much of this software can be used on VAX and meets the needs of not only the geotechnical, but the engineering, planning, and environmental offices.

Definitions

Aquifer, confined and unconfined; artesian; aquitard; aquiclude.

Aquifer.—A body of rock that is sufficiently permeable to conduct ground water and to yield economically significant quantities of water to wells and springs.

- Confined aquifer.—An aquifer bounded above and below by impermeable beds, or beds of distinctly lower permeability than that of the aquifer itself. An aquifer containing confined ground water.

- Unconfined aquifer.—An aquifer having a water table. An aquifer containing unconfined ground water.

Artesian.—An adjective referring to ground-water confined under hydrostatic pressure.

Artesian Aquifer.—See Confined Aquifer.

Aquitard.—A confining bed that retards but does not prevent the flow of water to or from an adjacent aquifer; a leaky confining bed. It does not readily yield water to wells or springs, but may serve as a storage unit for ground water.

Aquiclude.—A body of relatively impermeable rock or soil that is capable of absorbing water slowly but functions as an upper or lower boundary of an aquifer and does not transmit ground water rapidly enough to a well or spring.

Water level—regional, perched, zones of artesian, saturation, fracture flowage.

Water Table (Water Level).—The surface between the zone of saturation and the zone of aeration; that surface of a body of unconfined ground water at which the pressure is equal to that of the atmosphere.

Zone of Aeration.—Subsurface zone containing water under pressure less than that of the atmosphere, including water held by capillarity and containing air or gases generally under atmospheric pressure. This zone is limited above by the land surface and below by the surface of the zone of saturation.

Saturation.—The maximum possible content of water in the pore space of rock or soil.

Zone of Saturation.—A subsurface zone in which all the interstices are filled with water under pressure greater than that of the atmosphere. Although the zone may contain gas-filled interstices or interstices filled with fluid other than water, it is still considered saturated. This zone is separated from the zone of aeration by the water table.

Piezometric/Potentiometric surfaces

Piezometric/Potentiometric Surface.—An imaginary surface representing the total head of ground-water and defined by the level to which water will rise in a well. The water table is a particular potentiometric surface.

Piezometer.—A special type of observation well so finished as to permit the measurement of the water level in a particular stratum or zone.

REFERENCES

Morrison, Robert D., *Ground Water Monitoring Technology Procedures,* Equipment, and Application, Copyright 1983 by Timco Manufacturing Inc., Prairie du Sac WI.

Bureau of Reclamation, *Ground Water Manual,* A Water Resources Technical Publication, U.S. Department of the Interior, United States Government Printing Office, Washington D.C., 1977.

Stevens Water Resources Data Book, 3rd Edition, edited and published by Leupold and Stevens Inc., P.O. Box 688, Beaverton, OR 97005.

Driscoll, Fletcher G., *Ground Water and Wells,* 4th edition published by Johnson Division, UCP Inc., St. Paul MN 55165, 1975.

American Geological Institute, *Glossary of Geology,* Copyright 1972, 2201 M Street NW, Washington, D.C. 20037, 3rd edition reprinted 1987.

BIBLIOGRAPHY

[1] Bureau of Reclamation, *Water Measurement Manual,* A Water Resources Technical Publication, U.S. Department of the Interior, United States Government Printing Office, Washington DC., 1986.

Chapter 10

GUIDELINES FOR CORE LOGGING

These are the guidelines for core logging. They have been reviewed previously by most geologists, designers, and materials specialists at the Denver office and at various field offices. This section was prepared by an ad hoc committee following the geologist meeting in April 1984. The committee revised and expanded a draft which previously had been presented to, and worked on by, the core logging committee at the 1983 Geologist Conference. These guidelines incorporate and present: data recommended by the AEG (Association of Engineering Geologists) and have been forwarded to the AEG Rock Logging Subcommittee; procedures and methods used or proposed by some field offices; and are equally appropriate for "standard" Reclamation log forms, the new NGEOSUB computerized log forms, and many of the modified log forms used by geology staffs in various Reclamation offices.

These guidelines are compatible with the work of the Reclamation Nomenclature Committee and may be implemented immediately by any offices which wish to do so. However, before these are established as standards, constructive criticism, proposed revisions, expanded discussions, and new additions are encouraged and solicited. Please furnish any comments from your review and suggestions for improvement to the Denver Office, attention: Geology Branch, D-3610.

General

Introduction

This chapter provides the inexperienced logger with basic methods for performing engineering geology core logging; examples and instructions pertaining to format, descriptive data and techniques; and procedures for working with drillers to obtain the best data, care of recovered core, and water testing in drill holes. It serves as a reference for experienced loggers to improve their techniques and train others. Most of the discussions and examples shown pertain to logging rock core, but many discussions are applicable to logging soil core, standard penetration resistance logs, and drive tube sampling.

Purpose, Use, and Importance of Quality Core Logging

The ability of a foundation to accommodate the loads imposed by structures depends primarily on the deformability, strength, and ground-water conditions of the foundation materials. It is imperative to develop properly, standardize, and accurately portray geologic design data and analytical procedures. To do this, foundation data reported in geologic logs not only must be accurate, consistently recorded, and concise, but also must provide quantitative and qualitative descriptions.

Logs provide the fundamental data from which most subsequent conclusions regarding foundations are based. These conclusions may result in the need for additional exploration or testing, final design criteria, treatment design, methods of construction, and eventually the evaluation of structure performance. A Log may present important data for immediate interpretations or use, or it may provide data that are used over a period of years. It may be used to delineate existing foundation conditions, changes over time to the foundation or structure, serve as part of contract documents, and may be used as evidence in negotiations and/or in court to resolve contract disputes.

For engineering geology purposes, the basic objectives of logging core is to provide a factual, accurate, and concise record of the important geological and physical characteristics of engineering significance. Those characteristics which influence deformability, strength, and water conditions must be recorded adequately for future interpretations and analyses. Reclamation has adopted recognized indexes, nomenclature, standard descriptors and descriptive criteria, and quantified alphanumeric descriptors for physical properties to ensure that these data are recorded uniformly, consistently, and accurately. Use of alphanumeric descriptors and indexes permits digitizing of data for computer analysis. These descriptors, descriptive criteria, examples, and supporting discussions are provided in Chapters 3, 4, and 5.

Explorations should be logged or, as a minimum, reviewed by an experienced engineering geologist. The logger should be well aware of the multiple use of the log, and the needs and interests of technically diverse users. The experienced logger recognizes the often singular and primary purpose of the individual drill hole — to answer specific engineering geology questions and to determine physical properties — as well as the subordinate interests of others with varied geological backgrounds including geotechnical engineers, contract drillers, construction personnel, and contract lawyers. An experienced logger tailors the log to meet these needs, describing some seemingly minor features or conditions which he or she knows have engineering significance, and excluding petrologic features or geologic conditions having only minor or academic interest. On the other hand, less experienced loggers may have a tendency to concentrate on unnecessary garnishment, use technical terms not understood by others without a glossary, or produce an enormously detailed log which ignores the engineering geology considerations and perhaps the purpose for completing the drill hole. Adequate descriptions of recovered cores and samples can be prepared solely through visual or hand specimen examination of the core with the aid of simple field tests. Detailed microscopic or laboratory testing to define rock type or mineralogy generally are necessary only in special cases.

The purpose of drilling and logging is to secure evidence of the in-place condition of the soil or rock mass. Any core condition, core loss, or damage due to the type of bit, barrel or other equipment used, or due to improper techniques used in the drilling and handling processes should be described by the logger. Such factors may have a marked effect on the amount and condition of the core recovered, particularly in soft, friable, weathered, intensely fractured materials, or zones of shearing. Therefore, geologic logs require both the adequate description of materials and a detailed summary of drilling equipment, methods and conditions that may provide significant engineering data or be useful for geologic interpretations.

Format and Required Data for the Final Geologic Log

Organization of the Log

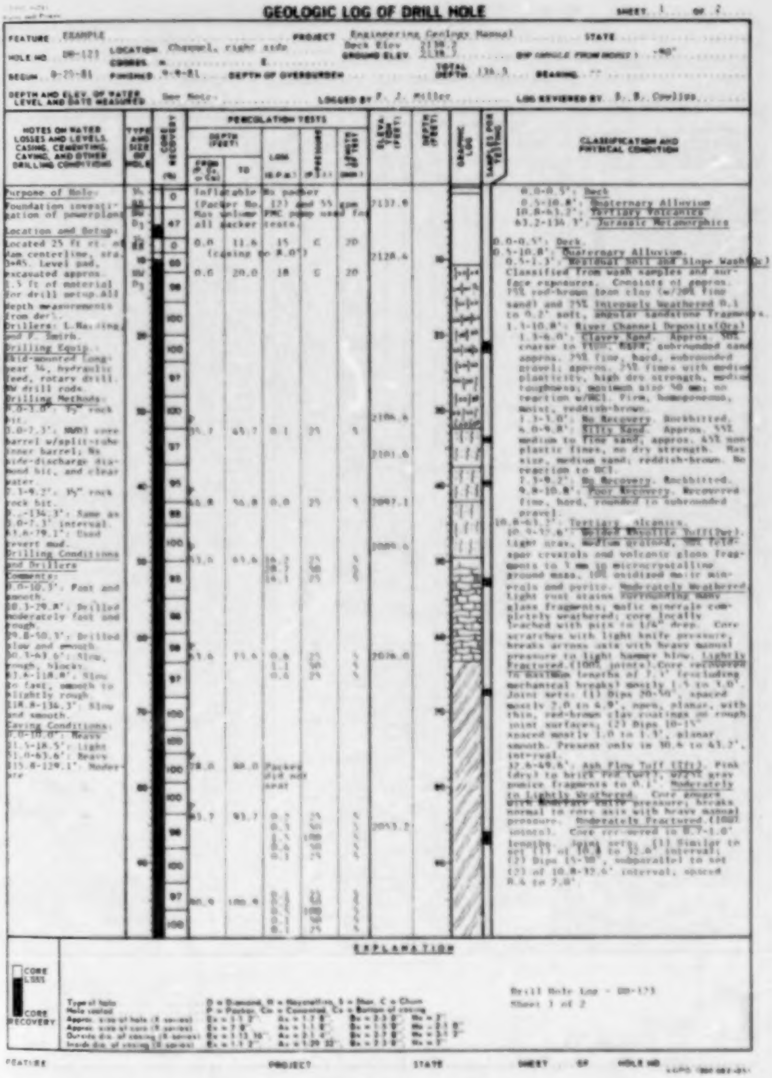
Data necessary for complete geologic logs of drill holes require adequate descriptions of recovered surficial deposits and bedrock, a detailed summary of drilling methods and conditions, and recording appropriate physical characteristics and indexes to ensure that adequate engineering data are available for geologic interpretation and analyses. The current Reclamation log (forms 7-1337, 7M-1337 for drill holes; 7-1334 or 7M-1334 for PR (SPT) holes; or the computer-generated forms) are divided into five basic sections: a heading block; a left-hand column for notes; a center column for indexes, additional notes, water tests and graphics; a right-hand column for classification and physical conditions; and a comments/explanation block at the bottom. Data required for each column are described in the following discussion and the referenced example logs. Log DH-123, figures 10-1 and 10-2 are the most complete or preferred example; other variations are presented, but in some cases are not complete or are not in the preferred format. However, they are actual logs used by others.

Heading

The heading block at the top of the previously referenced forms provides spaces for supplying identifying information as to project, feature, hole number, location, elevation, bearing and plunge of hole, dates started and completed, and the name(s) of the person(s) responsible for logging and review. The plunge of the hole is shown as dip, angle from horizontal. Use a "U" for up holes, not a plus sign (+). Spaces for summary data such as depth to bedrock and water levels are provided also. All of this information is important; any omissions should be justified. Below the heading, the body of the log form is divided into a series of columns covering the various kinds of information required according to the type of exploratory hole.

Data Required for the Left-Hand "Drilling Notes" Column

Data for the left-hand column of all drill hole logs whether for large-diameter sampling, Standard Penetration Tests,



GEOLOGIC LOG OF DRILL HOLE

SHEET 1 OF 2

FEATURE EXAMPLE

PROJECT Engineering Geology Manual

HOLE NO. DH-123

LOCATION Channel, right side

BEGUN 9-25-81

FINISHED 9-9-81

TOTAL DEPTH 134.3

LOGGED BY F. J. Miller

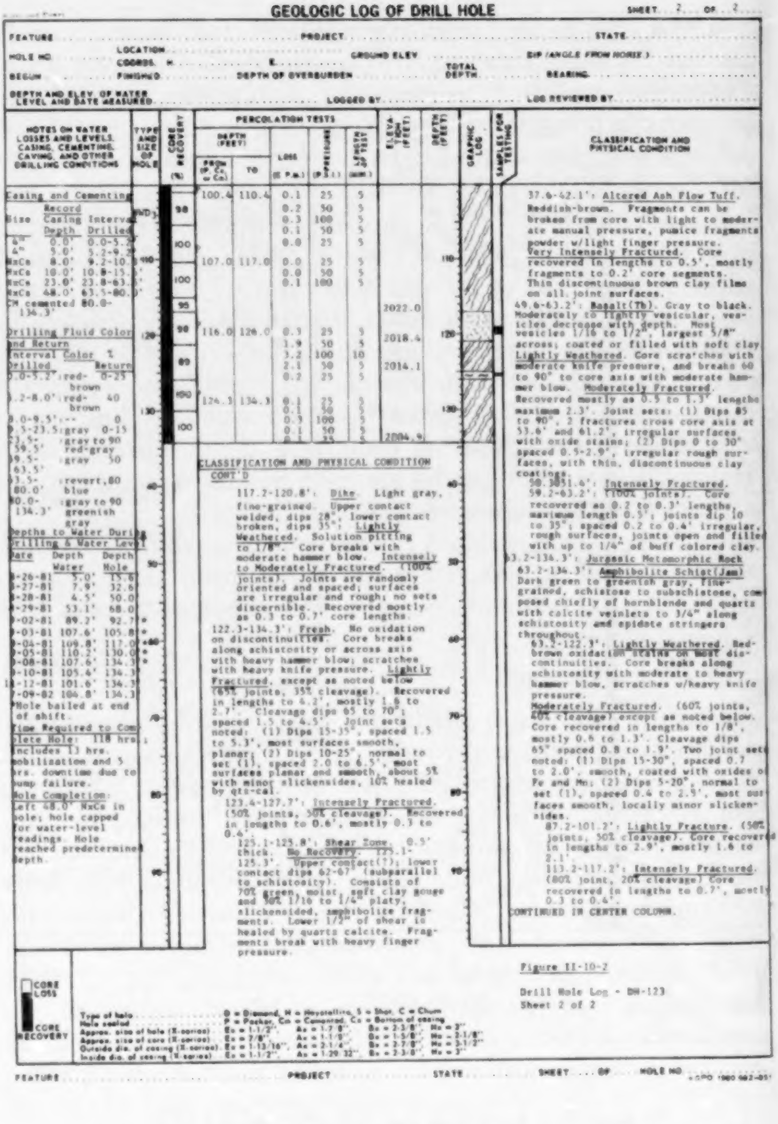
LOG REVIEWED BY S. B. Cowlins

PERCOLATION TESTS

CLASSIFICATION AND PHYSICAL CONDITION

EXPLANATION

Figure 10-1. Drill hole log, DH-123, sheet 1 of 2.



GEOLOGIC LOG OF DRILL HOLE — SHEET 2 OF 2

FEATURE .... PROJECT .... STATE ....
HOLE NO. .... LOCATION .... COORDS. N. .... E. .... GROUND ELEV. .... DIP (ANGLE FROM HORIZ.) ....
BEGUN .... FINISHED .... DEPTH OF OVERBURDEN .... TOTAL DEPTH .... BEARING ....
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED .... LOGGED BY .... LOG REVIEWED BY ....

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS

Casing and Cementing Record

Size	Casing Depth	Interval Drilled
6"	0.0'	0.0-5.2
4"	5.0'	5.2-9.2
NxCs	8.0'	9.2-10.
HxCs	10.0'	10.8-15.
NxCs	23.0'	23.8-63.
NxCs	48.0'	63.5-80.

CM cemented 80.0-134.3'

Drilling Fluid Color and Return

Interval Drilled	Color	% Return
.0-5.2'	red-brown	0-25
.2-8.0'	red-brown	40
.0-9.5'	--	0
.5-23.5	gray	0-15
3.5-59.5'	gray to red-gray	90
9.5-63.5'	gray	50
3.5-80.0'	revert, blue	80
0.0-134.3'	gray to greenish gray	90

Depths to Water During Drilling & Water Level

Date	Depth Water	Depth Hole
8-26-81	5.0'	15.6
8-27-81	7.9'	32.6
8-28-81	4.5'	50.0
8-29-81	53.1'	68.0
-02-81	89.2'	92.7 *
-03-81	107.6'	105.8 *
-04-81	109.8'	117.0 *
-05-81	110.2'	130.0 *
-08-81	107.6'	134.3 *
-10-81	105.4'	134.3
1-12-81	101.6'	134.3
-09-82	104.8'	134.3

*Hole bailed at end of shift.

Time Required to Complete Hole: 118 hrs.; includes 13 hrs. mobilization and 5 hrs. downtime due to pump failure.

Hole Completion: Left 48.0' NxCs in hole; hole capped for water-level readings. Hole reached predetermined depth.

TYPE AND SIZE OF HOLE: NXD

CORE RECOVERY (%): 98, 100, 100, 95, 90, 89, 100, 100

PERCOLATION TESTS

Depth (feet) From	To	Loss (G.P.M.)	Pressure (P.S.I.)	Length of test (min.)	Elevation (feet)
100.4	110.4	0.1	25	5	
		0.2	50	5	
		0.3	100	5	
		0.1	50	5	
		0.0	25	5	
107.0	117.0	0.0	25	5	
		0.0	50	5	
		0.1	100	5	
					2022.0
116.0	126.0	0.3	25	5	2018.4
		1.9	50	5	
		3.2	100	10	
		2.1	50	5	2014.1
		0.2	25	5	
124.3	134.3	0.1	25	5	
		0.1	50	5	
		0.3	100	5	
		0.1	50	5	
		0.1	25	5	2004.9

DEPTH (FEET): 110, 120, 130

CLASSIFICATION AND PHYSICAL CONDITION

37.6-42.1': Altered Ash Flow Tuff. Reddish-brown. Fragments can be broken from core with light to moderate manual pressure, pumice fragments powder w/light finger pressure. Very Intensely Fractured. Core recovered in lengths to 0.5', mostly fragments to 0.2' core segments. Thin discontinuous brown clay films on all joint surfaces.

49.6-63.2': Basalt(Tb). Gray to black. Moderately to lightly vesicular, vesicles decrease with depth. Most vesicles 1/16 to 1/2", largest 5/8" across; coated or filled with soft clay. Lightly Weathered. Core scratches with moderate knife pressure, and breaks 60 to 90° to core axis with moderate hammer blow. Moderately Fractured. Recovered mostly as 0.5 to 1.3' lengths maximum 2.3'. Joint sets: (1) Dips 85 to 90°, 2 fractures cross core axis at 53.6' and 61.2', irregular surfaces with oxide stains; (2) Dips 0 to 30° spaced 0.5-2.9', irregular rough surfaces, with thin, discontinuous clay coatings.

50.3051.6': Intensely Fractured.
59.2-63.2': (100% joints). Core recovered as 0.2 to 0.3' lengths, maximum length 0.5'; joints dip 10 to 35°; spaced 0.2 to 0.4' irregular, rough surfaces, joints open and filled with up to 1/4" of buff colored clay.

3.2-134.3': Jurassic Metamorphic Rock
63.2-134.3': Amphibolite Schist(Jam) Dark green to greenish gray, fine-grained, schistose to subschistose, composed chiefly of hornblende and quartz with calcite veinlets to 3/4" along schistosity and epidote stringers throughout.

63.2-122.3': Lightly Weathered. Red-brown oxidation stains on most discontinuities. Core breaks along schistosity with moderate to heavy hammer blow, scratches w/heavy knife pressure.

Moderately Fractured. (60% joints, 40% cleavage) except as noted below. Core recovered in lengths to 1/8', mostly 0.6 to 1.3'. Cleavage dips 65° spaced 0.8 to 1.9'. Two joint sets noted: (1) Dips 15-30°, spaced 0.7 to 2.0', smooth, coated with oxides of Fe and Mn; (2) Dips 5-20°, normal to set (1), spaced 0.4 to 2.5', most surfaces smooth, locally minor slickensides.

87.2-101.2': Lightly Fracture. (50% joints, 50% cleavage). Core recovered in lengths to 2.9', mostly 1.6 to 2.1'.

113.2-117.2': Intensely Fractured. (80% joint, 20% cleavage) Core recovered in lengths to 0.7', mostly 0.3 to 0.4'.

CONTINUED IN CENTER COLUMN.

CLASSIFICATION AND PHYSICAL CONDITION CONT'D

117.2-120.8': Dike. Light gray, fine-grained. Upper contact welded, dips 28°, lower contact broken, dips 35°; Lightly Weathered. Solution pitting to 1/8". Core breaks with moderate hammer blow. Intensely to Moderately Fractured. (100% joints). Joints are randomly oriented and spaced; surfaces are irregular and rough; no sets discernible. Recovered mostly as 0.3 to 0.7' core lengths.

122.3-134.3': Fresh. No oxidation on discontinuities. Core breaks along schistosity or across axis with heavy hammer blow; scratches with heavy knife pressure. Lightly Fractured, except as noted below (65% joints, 35% cleavage). Recovered in lengths to 4.2', mostly 1.6 to 2.7'. Cleavage dips 65 to 70°; spaced 1.5 to 4.5'. Joint sets noted: (1) Dips 15-35°, spaced 1.5 to 5.3', most surfaces smooth, planar; (2) Dips 10-25°, normal to set (1), spaced 2.0 to 6.5', most surfaces planar and smooth, about 5% with minor slickensides, 10% healed by qtz-cal.

123.4-127.7': Intensely Fractured. (50% joints, 50% cleavage). Recovered in lengths to 0.6', mostly 0.3 to 0.4'.

125.1-125.8': Shear Zone. 0.5' thick. No Recovery. 125.1-125.3'. Upper contact(?); lower contact dips 62-67° (subparallel to schistosity). Consists of 70% green, moist, soft clay gouge and 30% 1/16 to 1/4" platy, slickensided, amphibolite fragments. Lower 1/2" of shear is healed by quartz calcite. Fragments break with heavy finger pressure.

☐ CORE LOSS
■ CORE RECOVERY

Type of hole .... D = Diamond, H = Hoystellite, S = Shot, C = Churn
Hole sealed .... P = Packer, Cm = Cemented, Cs = Bottom of casing
Approx. size of hole (X-series) .... Ex = 1-1/2", Ax = 1-7/8", Bx = 2-3/8", Nx = 3"
Approx. size of core (X-series) .... Ex = 7/8", Ax = 1-1/8", Bx = 1-5/8", Nx = 2-1/8"
Outside dia. of casing (X-series) .... Ex = 1-13/16", Ax = 2-1/4", Bx = 2-7/8", Nx = 3-1/2"
Inside dia. of casing (X-series) .... Ex = 1-1/2", Ax = 1-29/32", Bx = 2-3/8", Nx = 3"

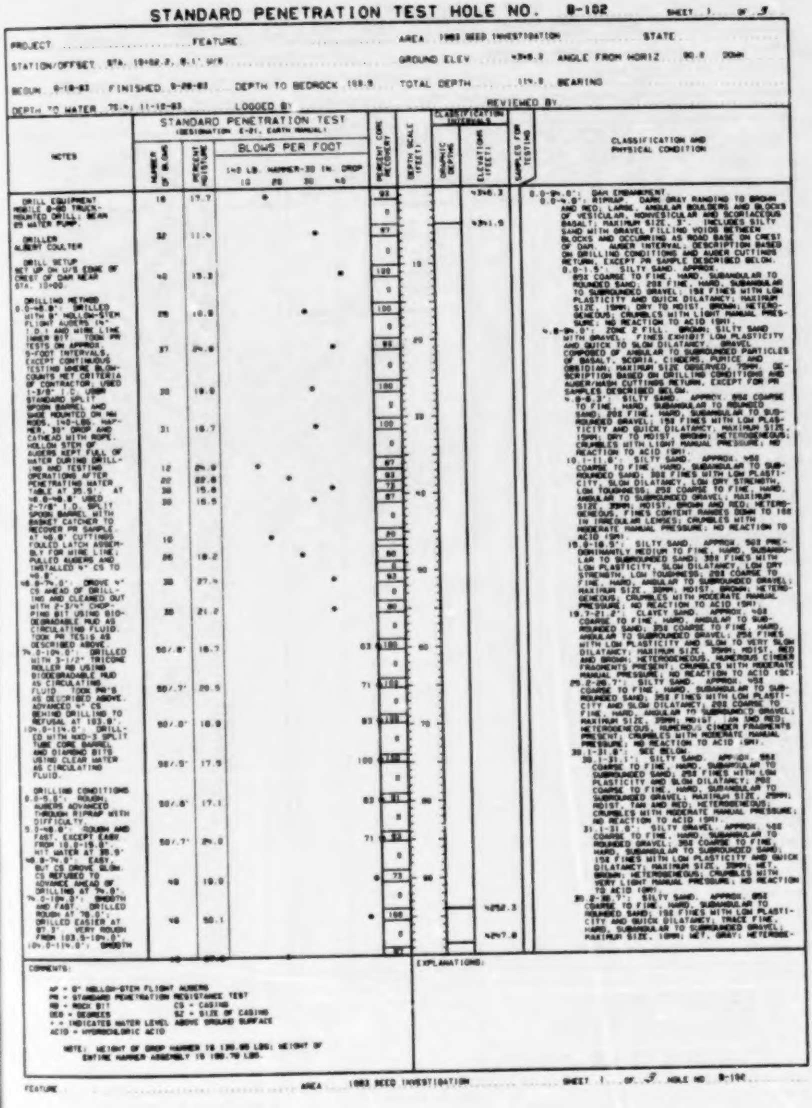
Figure II-10-2

Drill Hole Log - DH-123
Sheet 2 of 2

FEATURE .... PROJECT .... STATE .... SHEET ..... OF ..... HOLE NO. ....

GPO 1980 662-051

Figure 10-1. Drill hole log, DH-123, sheet 2 of 2. (continued)



STANDARD PENETRATION TEST HOLE NO. B-102 SHEET 1 OF 3

PROJECT .... FEATURE .... AREA 1983 SEED INVESTIGATION STATE ....
STATION/OFFSET STA. 10+02.2, 8.1' U/S GROUND ELEV 4348.3 ANGLE FROM HORIZ 90.0 DOWN
BEGUN 9-18-83 FINISHED 9-28-83 DEPTH TO BEDROCK 103.9 TOTAL DEPTH 114.0 BEARING ....
DEPTH TO WATER 75.4; 11-10-83 LOGGED BY .... REVIEWED BY ....

NOTES
STANDARD PENETRATION TEST
(DESIGNATION E-21, EARTH MANUAL)
NUMBER OF BLOWS
PERCENT MOISTURE
BLOWS PER FOOT
140 LB. HAMMER-30 IN. DROP
10
20
30
40
PERCENT CORE RECOVERY
DEPTH SCALE (FEET)
CLASSIFICATION INTERVALS
GRAPHIC DEPTHS
ELEVATIONS (FEET)
SAMPLES FOR TESTING
CLASSIFICATION AND PHYSICAL CONDITION

COMMENTS:

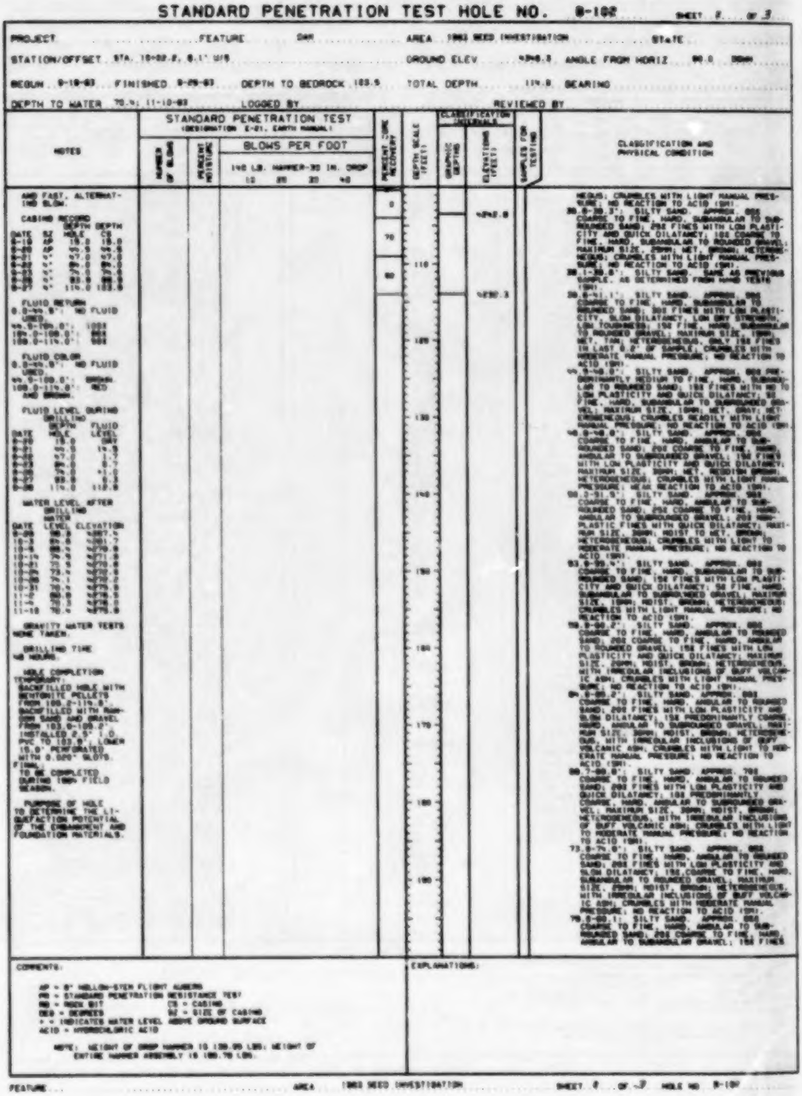
AF = 8" HOLLOW-STEM FLIGHT AUGERS
PR = STANDARD PENETRATION RESISTANCE TEST
RB = ROCK BIT CS = CASING
DEG = DEGREES SZ = SIZE OF CASING
+ = INDICATES WATER LEVEL ABOVE GROUND SURFACE
ACID = HYDROCHLORIC ACID

NOTE: WEIGHT OF DROP HAMMER IS 139.85 LBS; WEIGHT OF ENTIRE HAMMER ASSEMBLY IS 189.70 LBS.

EXPLANATIONS:

FEATURE .... AREA 1983 SEED INVESTIGATION SHEET 1 OF 3 HOLE NO. B-102

Figure 10-2. Drill hole log, B-102, for Standard Penetration Test, sheet 1 of 3.



STANDARD PENETRATION TEST HOLE NO. B-102 SHEET 2 OF 3

PROJECT
FEATURE DAM
AREA 1983 SEED INVESTIGATION
STATE
STATION/OFFSET
GROUND ELEV
ANGLE FROM HORIZ
BEGUN
FINISHED
DEPTH TO BEDROCK
TOTAL DEPTH
BEARING
DEPTH TO WATER
LOGGED BY
REVIEWED BY

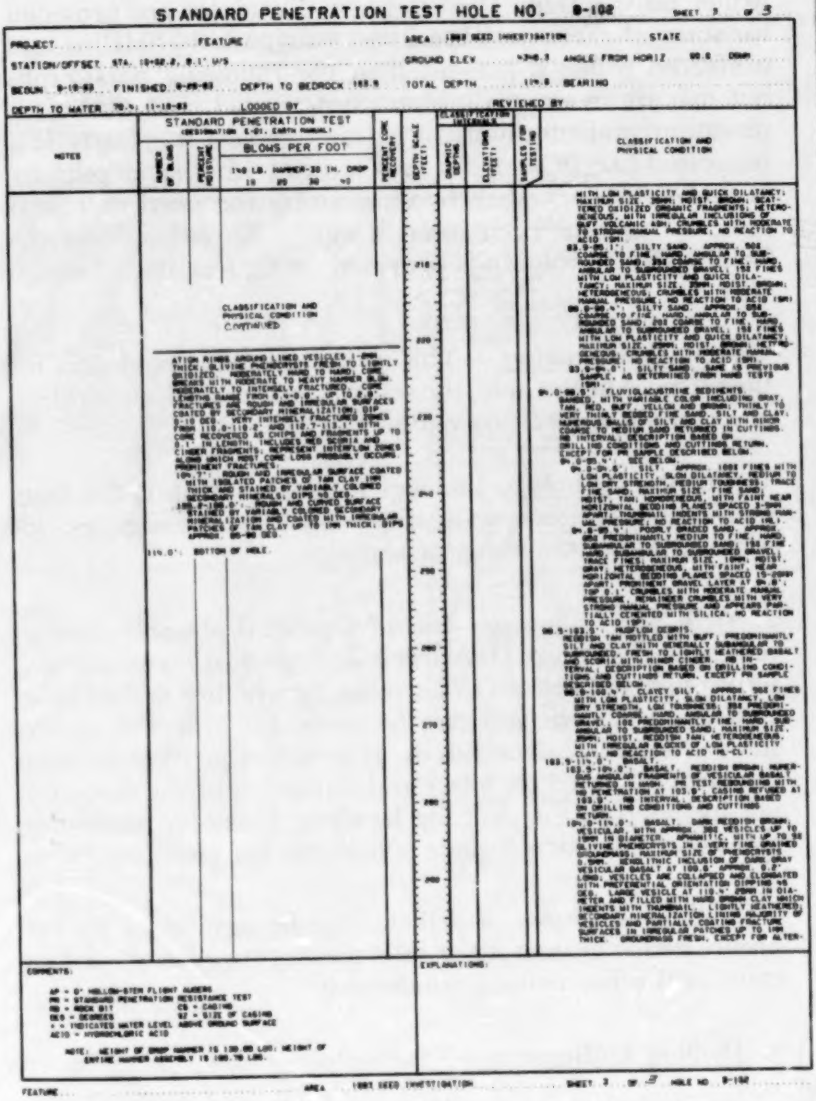
NOTES	STANDARD PENETRATION TEST (DESIGNATION E-21, EARTH MANUAL) NUMBER OF BLOWS	PERCENT MOISTURE	BLOWS PER FOOT 140 LB. HAMMER-30 IN. DROP 10 20 30 40	PERCENT CORE RECOVERY	DEPTH SCALE (FEET)	CLASSIFICATION INTERVALS GRAPHIC DEPTHS	ELEVATIONS (FEET)	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION

COMMENTS:

EXPLANATIONS:

FEATURE AREA 1983 SEED INVESTIGATION SHEET 2 OF 3 HOLE NO. B-102

Figure 10-2. Drill hole log, B-102, for Standard Penetration Test, sheet 2 of 3. (continued)



STANDARD PENETRATION TEST HOLE NO. B-102 SHEET 3 OF 3

PROJECT ... FEATURE ... AREA ... STATE

STATION/OFFSET ... GROUND ELEV ... ANGLE FROM HORIZ ... BEARING

BEGUN ... FINISHED ... DEPTH TO BEDROCK ... TOTAL DEPTH

DEPTH TO WATER ... LOGGED BY ... REVIEWED BY

NOTES	STANDARD PENETRATION TEST (DESIGNATION E-21, EARTH MANUAL)			PERCENT CORE RECOVERY	DEPTH SCALE (FEET)	CLASSIFICATION INTERVALS		SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
	NUMBER OF BLOWS	PERCENT MOISTURE	BLOWS PER FOOT 140 LB. HAMMER-30 IN. DROP 10 20 30 40			GRAPHIC DEPTHS	ELEVATIONS (FEET)		

CLASSIFICATION AND PHYSICAL CONDITION CONTINUED

COMMENTS:

AP = 6" HOLLOW-STEM FLIGHT AUGERS
PR = STANDARD PENETRATION RESISTANCE TEST
RB = ROCK BIT
CS = CASING
DEG = DEGREES
SZ = SIZE OF CASING
+ = INDICATES WATER LEVEL ABOVE GROUND SURFACE
ACID = HYDROCHLORIC ACID

NOTE: WEIGHT OF DROP HAMMER IS 139.80 LBS; WEIGHT OF ENTIRE HAMMER ASSEMBLY IS 180.70 LBS.

EXPLANATIONS:

FEATURE ... AREA ... SHEET 3 OF 3 HOLE NO. B-102

Figure 10-2. Drill hole log, B-102, for Standard Penetration Test, sheet 3 of 3. (continued)

rock core, or push-tube sampling logs, are similar. These data are to be provided from geologists' notes and field observations and information provided directly from the driller on the Daily Drill Reports. Examples are provided for some of these data headings; a suggested guideline and preferred order is presented in the following paragraphs but may differ depending on purpose and type of the exploration, and continuity of existing project standards. It is suggested that headers for data indicate whether depths are in feet or meters, thereby eliminating the need to repeat "ft" or "m" for each interval entry. An example of the Drilling Notes column is provided on figures 10-1 through 10-4.

General Information.—This includes headers and data for the purpose of the hole, the setup or site conditions, drillers, and drilling and testing equipment used.

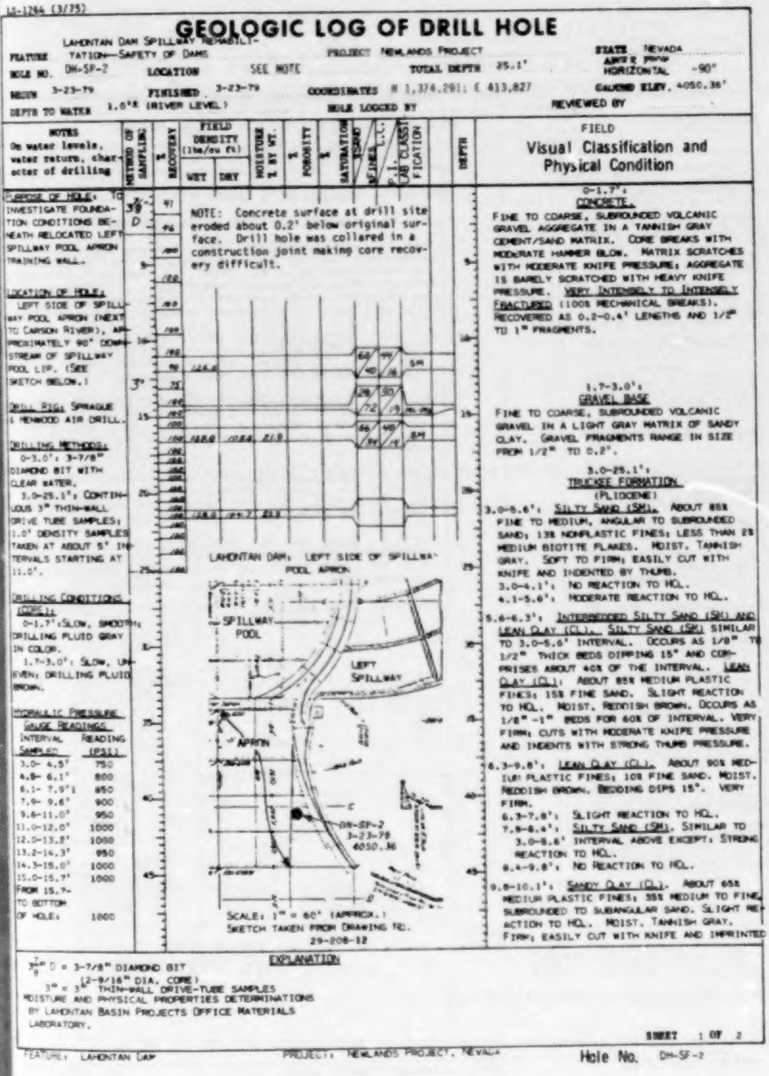
1. Purpose of hole.—Includes reason for drilling the hole, such as foundation investigation, materials investigation, instrumentation, sampling, or testing.

2. Drill Site or Setup.—Includes general physical description of the location of the drill hole. Information on unusual setups such as adjacent to a stream, or whether drilled from a barge, gallery or adit may be useful for others to understand the unusual conditions. If possible, provide location information based on offset and stationing of the feature if not included in the drill log heading. However, stationing and offset are not adequate substitutes for coordinates.

3. Drillers.—Names of drillers may be significant for reference or for evaluating or interpreting core losses, drilling rates, and other drilling conditions.

4. Drilling Equipment.

- Drill rig (make and model)
- Core barrel(s), tube(s), special samplers (type and size)
- Bits (type and size)
- Drill rods (type and size)
- Collars (type)



LS-1264 (3/75)

GEOLOGIC LOG OF DRILL HOLE

FEATURE LAHONTAN DAM SPILLWAY REHABILITATION—SAFETY OF DAMS
PROJECT NEWLANDS PROJECT
STATE NEVADA
HOLE NO. DH-SP-2
LOCATION SEE NOTE
TOTAL DEPTH 25.1'
ANGLE FROM HORIZONTAL -90°
BEGUN 3-23-79
FINISHED 3-23-79
COORDINATES N 1,374,291; E 413,827
GROUND ELEV. 4050.36'
DEPTH TO WATER 1.0'± (RIVER LEVEL)
HOLE LOGGED BY
REVIEWED BY

NOTES On water levels, water return, character of drilling | METHOD OF SAMPLING | % RECOVERY | FIELD DENSITY (lbs/cu ft) WET | DRY | MOISTURE % BY WT. | % POROSITY | % SATURATION | % SAND / % FINES | L.L. / P.I. | LAB CLASSIFICATION | DEPTH | FIELD Visual Classification and Physical Condition

PURPOSE OF HOLE: TO INVESTIGATE FOUNDATION CONDITIONS BENEATH RELOCATED LEFT SPILLWAY POOL APRON TRAINING WALL.

LOCATION OF HOLE: LEFT SIDE OF SPILLWAY POOL APRON (NEXT TO CARSON RIVER), APPROXIMATELY 90' DOWNSTREAM OF SPILLWAY POOL LIP. (SEE SKETCH BELOW.)

DRILL RIG: SPRAGUE & HENWOOD AIR DRILL.

DRILLING METHODS:
0-3.0': 3-7/8" DIAMOND BIT WITH CLEAR WATER.
3.0-25.1': CONTINUOUS 3" THIN-WALL DRIVE TUBE SAMPLES; 1.0' DENSITY SAMPLES TAKEN AT ABOUT 5' INTERVALS STARTING AT 11.0'.

DRILLING CONDITIONS (CORE):
0-1.7': SLOW, SMOOTH; DRILLING FLUID GRAY IN COLOR.
1.7-3.0': SLOW, UNEVEN; DRILLING FLUID BROWN.

HYDRAULIC PRESSURE GAUGE READINGS

INTERVAL SAMPLED	READING (PSI)
3.0- 4.5'	750
4.5- 6.1'	800
6.1- 7.9'	850
7.9- 9.6'	900
9.6-11.0'	950
11.0-12.0'	1000
12.0-13.2'	1000
13.2-14.3'	950
14.3-15.0'	1000
15.0-15.7'	1000
FROM 15.7- TO BOTTOM OF HOLE:	1000

NOTE: Concrete surface at drill site eroded about 0.2' below original surface. Drill hole was collared in a construction joint making core recovery difficult.

LAHONTAN DAM: LEFT SIDE OF SPILLWAY POOL APRON

SCALE: 1" = 60' (APPROX.)
SKETCH TAKEN FROM DRAWING NO. 29-208-12

0-1.7':
CONCRETE.
FINE TO COARSE, SUBROUNDED VOLCANIC GRAVEL AGGREGATE IN A TANNISH GRAY CEMENT/SAND MATRIX. CORE BREAKS WITH MODERATE HAMMER BLOW. MATRIX SCRATCHES WITH MODERATE KNIFE PRESSURE; AGGREGATE IS BARELY SCRATCHED WITH HEAVY KNIFE PRESSURE. VERY INTENSELY TO INTENSELY FRACTURED (100% MECHANICAL BREAKS). RECOVERED AS 0.2-0.4' LENGTHS AND 1/2" TO 1" FRAGMENTS.

1.7-3.0':
GRAVEL BASE
FINE TO COARSE, SUBROUNDED VOLCANIC GRAVEL IN A LIGHT GRAY MATRIX OF SANDY CLAY. GRAVEL FRAGMENTS RANGE IN SIZE FROM 1/2" TO 0.2'.

3.0-25.1':
TRUCKEE FORMATION
(PLIOCENE)

3.0-5.6': SILTY SAND (SM). ABOUT 85% FINE TO MEDIUM, ANGULAR TO SUBROUNDED SAND; 13% NONPLASTIC FINES; LESS THAN 2% MEDIUM BIOTITE FLAKES. MOIST. TANNISH GRAY. SOFT TO FIRM; EASILY CUT WITH KNIFE AND INDENTED BY THUMB.
3.0-4.1': NO REACTION TO HCL.
4.1-5.6': MODERATE REACTION TO HCL.

5.6-6.3': INTERBEDDED SILTY SAND (SM) AND LEAN CLAY (CL). SILTY SAND (SM) SIMILAR TO 3.0-5.6' INTERVAL. OCCURS AS 1/8" TO 1/2" THICK BEDS DIPPING 15° AND COMPRISES ABOUT 40% OF THE INTERVAL. LEAN CLAY (CL): ABOUT 85% MEDIUM PLASTIC FINES; 15% FINE SAND. SLIGHT REACTION TO HCL. MOIST. REDDISH BROWN. OCCURS AS 1/8"-1" BEDS FOR 60% OF INTERVAL. VERY FIRM; CUTS WITH MODERATE KNIFE PRESSURE AND INDENTS WITH STRONG THUMB PRESSURE.

6.3-9.8': LEAN CLAY (CL). ABOUT 90% MEDIUM PLASTIC FINES; 10% FINE SAND. MOIST. REDDISH BROWN. BEDDING DIPS 15°. VERY FIRM.
6.3-7.8': SLIGHT REACTION TO HCL.
7.8-8.4': SILTY SAND (SM). SIMILAR TO 3.0-5.6' INTERVAL ABOVE EXCEPT: STRONG REACTION TO HCL.
8.4-9.8': NO REACTION TO HCL.

9.8-10.1': SANDY CLAY (CL). ABOUT 65% MEDIUM PLASTIC FINES; 35% MEDIUM TO FINE, SUBROUNDED TO SUBANGULAR SAND. SLIGHT REACTION TO HCL. MOIST. TANNISH GRAY. FIRM; EASILY CUT WITH KNIFE AND IMPRINTED

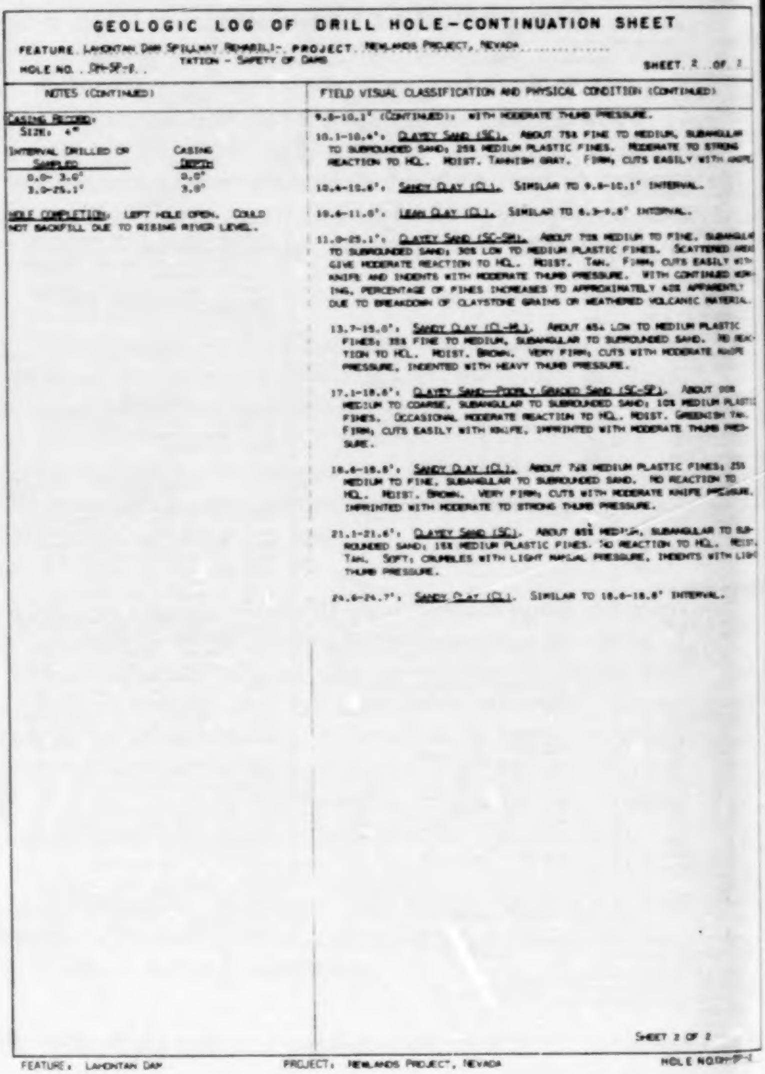
EXPLANATION

$3\frac{7}{8}$" D = 3-7/8" DIAMOND BIT (2-9/16" DIA. CORE)
3" = 3" THIN-WALL DRIVE-TUBE SAMPLES
MOISTURE AND PHYSICAL PROPERTIES DETERMINATIONS BY LAHONTAN BASIN PROJECTS OFFICE MATERIALS LABORATORY.

SHEET 1 OF 2

FEATURE: LAHONTAN DAM PROJECT: NEWLANDS PROJECT, NEVADA Hole No. DH-SP-2

Figure 10-3. Drill hole log, DH-SP-2, sheet 1 of 2.



GEOLOGIC LOG OF DRILL HOLE—CONTINUATION SHEET

FEATURE LAHONTAN DAM SPILLWAY REHABILI- PROJECT NEWLANDS PROJECT, NEVADA
TATION - SAFETY OF DAMS
HOLE NO. DH-SP-2 SHEET 2 OF 2

NOTES (CONTINUED)

CASING RECORD:
SIZE: 4"

INTERVAL DRILLED OR SAMPLED	CASING DEPTH
0.0- 3.0'	0.0'
3.0-25.1'	3.0'

HOLE COMPLETION: LEFT HOLE OPEN. COULD NOT BACKFILL DUE TO RISING RIVER LEVEL.

FIELD VISUAL CLASSIFICATION AND PHYSICAL CONDITION (CONTINUED)

9.8-10.1' (CONTINUED): WITH MODERATE THUMB PRESSURE.

10.1-10.4': CLAYEY SAND (SC). ABOUT 75% FINE TO MEDIUM, SUBANGULAR TO SUBROUNDED SAND; 25% MEDIUM PLASTIC FINES. MODERATE TO STRONG REACTION TO HCL. MOIST. TANNISH GRAY. FIRM; CUTS EASILY WITH KNIF

10.4-10.6': SANDY CLAY (CL). SIMILAR TO 9.8-10.1' INTERVAL.

10.6-11.0': LEAN CLAY (CL). SIMILAR TO 6.3-9.8' INTERVAL.

11.0-25.1': CLAYEY SAND (SC-SM). ABOUT 70% MEDIUM TO FINE, SUBANGULA TO SUBROUNDED SAND; 30% LOW TO MEDIUM PLASTIC FINES. SCATTERED ARE GIVE MODERATE REACTION TO HCL. MOIST. TAN. FIRM; CUTS EASILY WITH KNIFE AND INDENTS WITH MODERATE THUMB PRESSURE. WITH CONTINUED WORKING, PERCENTAGE OF FINES INCREASES TO APPROXIMATELY 40% APPARENTLY DUE TO BREAKDOWN OF CLAYSTONE GRAINS OR WEATHERED VOLCANIC MATERIA

13.7-15.0': SANDY CLAY (CL-ML). ABOUT 65% LOW TO MEDIUM PLASTIC FINES; 35% FINE TO MEDIUM, SUBANGULAR TO SUBROUNDED SAND. NO REACTION TO HCL. MOIST. BROWN. VERY FIRM; CUTS WITH MODERATE KNIFE PRESSURE, INDENTED WITH HEAVY THUMB PRESSURE.

17.1-18.6': CLAYEY SAND—POORLY GRADED SAND (SC-SP). ABOUT 90% MEDIUM TO COARSE, SUBANGULAR TO SUBROUNDED SAND; 10% MEDIUM PLASTI FINES. OCCASIONAL MODERATE REACTION TO HCL. MOIST. GREENISH TAN. FIRM; CUTS EASILY WITH KNIFE, IMPRINTED WITH MODERATE THUMB PRESSURE.

18.6-18.8': SANDY CLAY (CL). ABOUT 75% MEDIUM PLASTIC FINES; 25% MEDIUM TO FINE, SUBANGULAR TO SUBROUNDED SAND. NO REACTION TO HCL. MOIST. BROWN. VERY FIRM; CUTS WITH MODERATE KNIFE PRESSURE, IMPRINTED WITH MODERATE TO STRONG THUMB PRESSURE.

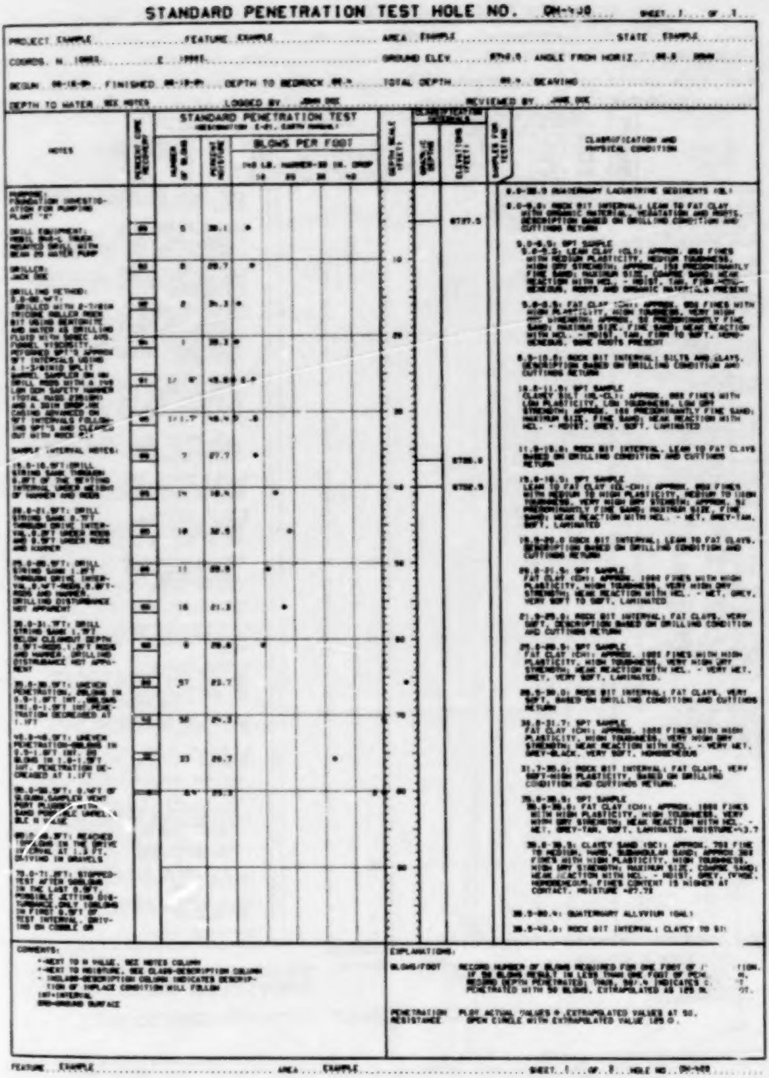
21.1-21.6': CLAYEY SAND (SC). ABOUT 85% MEDIUM, SUBANGULAR TO SUBROUNDED SAND; 15% MEDIUM PLASTIC FINES. NO REACTION TO HCL. MOIST. TAN. SOFT; CRUMBLES WITH LIGHT MANUAL PRESSURE, INDENTS WITH LIG THUMB PRESSURE.

24.6-24.7': SANDY CLAY (CL). SIMILAR TO 18.6-18.8' INTERVAL.

SHEET 2 OF 2

FEATURE: LAHONTAN DAM PROJECT: NEWLANDS PROJECT, NEVADA HOLE NO.DH-SP-

Figure 10-3. Drill hole log, DH-SP-2, sheet 2 of 2. (continued)

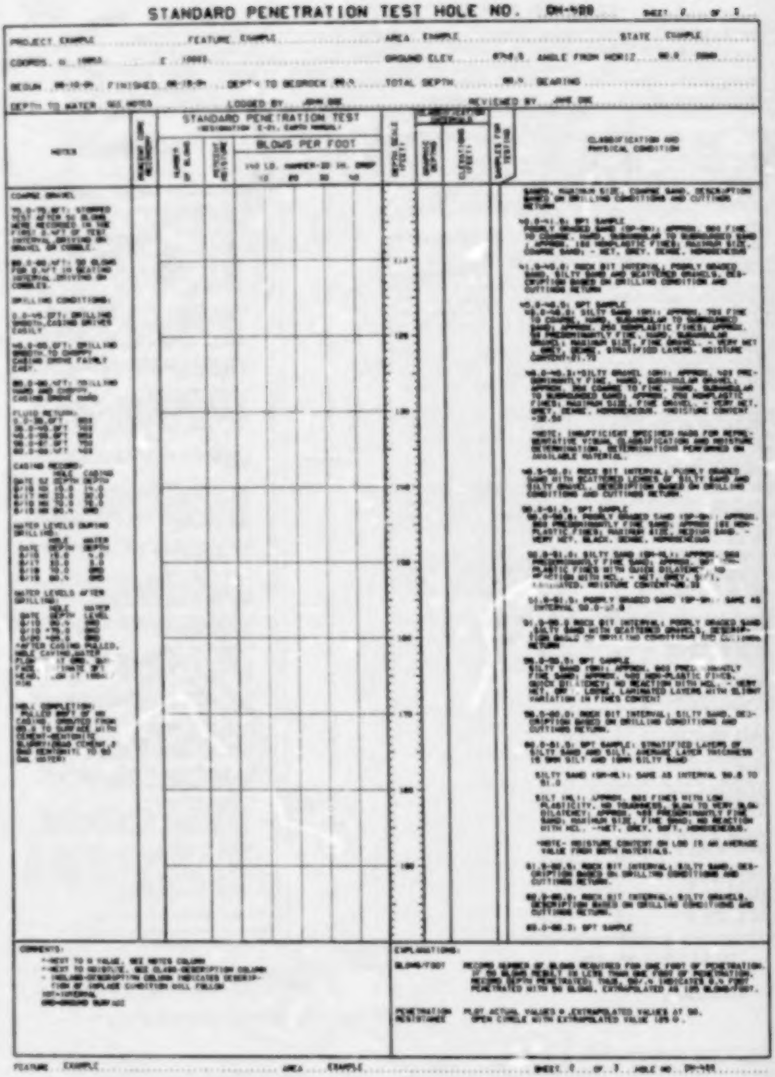


STANDARD PENETRATION TEST HOLE NO.

PROJECT ... FEATURE ... AREA ... STATE ...
COORDS. N ... E ... GROUND ELEV ... ANGLE FROM HORIZ ...
BEGUN ... FINISHED ... DEPTH TO BEDROCK ... TOTAL DEPTH ... BEARING ...
DEPTH TO WATER ... LOGGED BY ... REVIEWED BY ...

NOTES
STANDARD PENETRATION TEST
BLOWS PER FOOT
10
20
30
40
CLASSIFICATION AND PHYSICAL CONDITION
COMMENTS:
EXPLANATIONS:

Figure 10-4. Drill hole log, DH-400, sheet 1 of 3.



STANDARD PENETRATION TEST HOLE NO. DH-400

PROJECT EXAMPLE FEATURE EXAMPLE AREA EXAMPLE STATE EXAMPLE

COORDS. N. E. GROUND ELEV. ANGLE FROM HORIZ.

BEGIN FINISHED DEPTH TO BEDROCK TOTAL DEPTH BEARING

DEPTH TO WATER SEE NOTES LOGGED BY REVIEWED BY

STANDARD PENETRATION TEST

NOTES

BLOWS PER FOOT

140 LB. HAMMER-30 IN. DROP

10 20 30 40

CLASSIFICATION AND PHYSICAL CONDITION

COMMENTS:

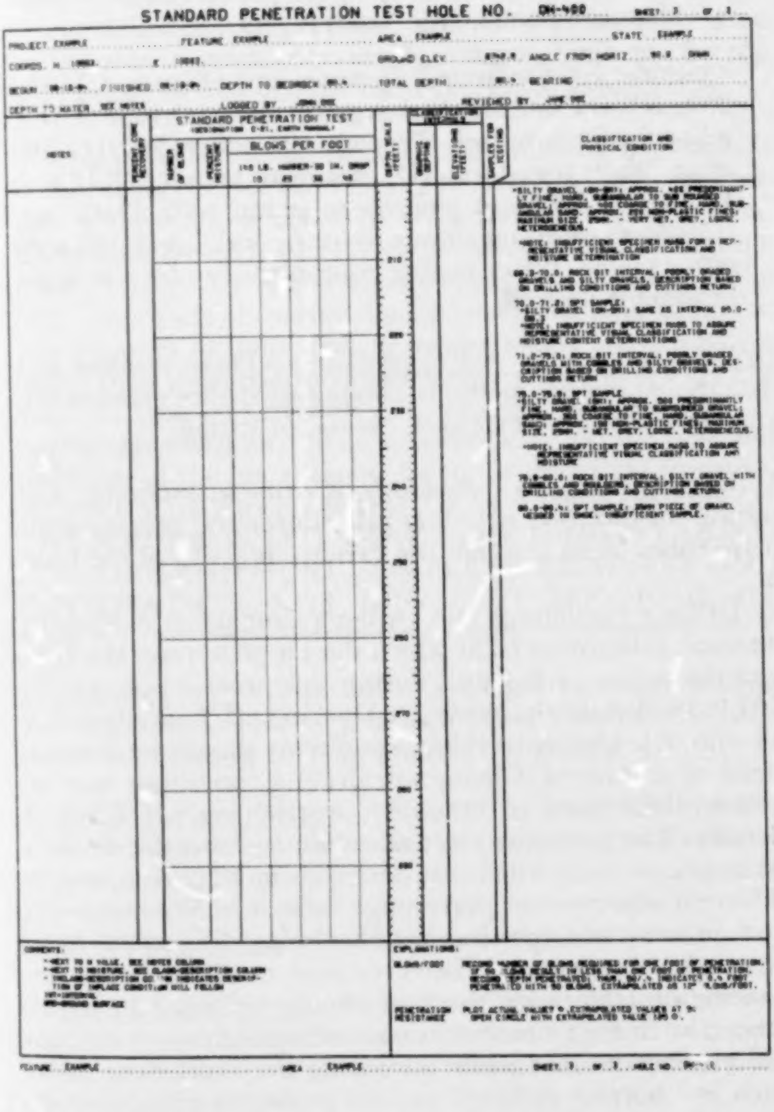
EXPLANATIONS:

BLOWS/FOOT

PENETRATION RESISTANCE

FEATURE EXAMPLE AREA EXAMPLE SHEET 2 OF 3 HOLE NO. DH-400

Figure 10-4. Drill hole log, DH-400, sheet 2 of 3. (continued)



STANDARD PENETRATION TEST HOLE NO. DH-400

PROJECT EXAMPLE FEATURE EXAMPLE AREA EXAMPLE STATE EXAMPLE

COORDS. N E GROUND ELEV. ANGLE FROM HORIZ

BEGUN FINISHED DEPTH TO BEDROCK TOTAL DEPTH BEARING

DEPTH TO WATER SEE NOTES LOGGED BY REVIEWED BY

NOTES	STANDARD PENETRATION TEST BLOWS PER FOOT 10 20 30 40	CLASSIFICATION AND PHYSICAL CONDITION

COMMENTS:

EXPLANATIONS:

FEATURE EXAMPLE AREA EXAMPLE

Figure 10-4. Drill hole log, DH-400, sheet 3 of 3. (continued)

- Water tests equipment (rod or pipe size, hose size, pump type and capacity, and relative position and elevation of pressure gauges), packers (type — mechanical, peneumatic, transducer)

Example: Skid-mounted Sprague and Henwood Model 250. NWD3 bottom discharge bit with a 5-foot (1.5m), split-tube inner barrel. NW rods with collars 5 feet (1.5m) apart. Water tested with NX pneumatic packer No. 12 with 1-1/4-inch (32 mm) pipe, Bean pump with 35-gal/min (159 liters/min) maximum volume, and 1-inch (25 mm) water meter. Water testing equipment can be a separate heading if desired.

Drilling Procedures and Conditions.—These headers and data should include methods, conditions, driller's comments, and records for water losses, caving, or casing.

1. Drilling Methods.—Synopsis of drilling, sampling, and testing procedures, including procedures and pressures for drive tubes, used through the various intervals of the hole.

2. Drilling Conditions and Driller's Comments.—Note by interval, relative speed at which the bit penetrates the rock and the action of the drill during this process [i.e., 105.6-107.9: Drilled slowly, moderate blocking off, hole advancing 15 min/ft]. Unusual drilling conditions should be summarized or combined. Changes in drilling conditions may indicate differences in lithology, weathering, or fracture density. The geologist must take into account the driller's descriptions; each driller may describe similar conditons with different adjectives or percentage estimates. Note locations and quantity of explosives used to help advance the hole. Any other comments relative to ease or difficulty of advancing or maintining the hole should be noted by depth intervals. Drillers' comments must adequately describe conditions encountered while advancing the hole. Statements such as "normal drilling" or "no problems encountered" are not acceptable.

Differences in drilling speeds, pressures, and penetration rates may be related to the relative hardness and density of materials. Abrupt changes in drilling time may identify lithologic changes or breaks and also may pinpoint soft or hard interbeds within larger units. Often, these may be correlated with geophysical logs. If the driller provides useful and accurate records of drilling conditions and procedures, a geologist skilled in interpretaiton, and using all available data, may be able to produce an accurate log and indicate the top and bottom of key marker horizons, even without core.

Drilling progress should be recorded while drilling—it aids in improving recovery by relating recovery to optimum pressures and speeds, as well as offering data for interpretation. Therefore, for each run the driller should record the time when starting to drill and when stopping to come out of the hole. There are, however, limitations to drilling progress. The majority of these drilling progress data are qualitative rather than quantitative values. Controlling factors are not only the type of materials encountered, but also may be mechanical variables. These variables may include type and condition of the bit, rotation speed, drilling fluid pressure, etc. ONE MUST REMEMBER THAT THE PURPOSE OF THE BORING IS TO OBTAIN THE HIGHEST QUALITY CORE AND MOST COMPLETE RECOVERY AND INFORMATION, NOT JUST FEET PER HOUR OR SHIFT.

3. Drilling Fluid.—Type and where used (including drilling fluid additives). This may be combined with or discussed under the heading Drilling Methods if desired.

4. Drilling Fluid Return.—Include Interval/Percent Return. Drilling fluid return may be combined with color if desired.

5. Drill Fluid Color.—Include Interval/Color.

6. Caving Conditions.—Intervals of cave with appropriate remarks about the relative amount of caving are to be noted. When possible, report the actual caving interval rather than the depth of the hole.

7. Casing Record.—Casing depth is the depth of casing at the start of the drilled interval (see the example below).

8. Flight Avancement (push-tube or SPT applications).—Include flight depth/interval sampled.

9. Cementing Record.—Note all intervals cemented and if intervals were cemented more than once. This may be combined with casing record as shown below:

Example of casing and cementing record:

Interval drilled (ft)	Size (in)	Casing depth (ft)
0.0 - 2.3	6 Cs	0.0
2.3 - 4.5	6 Cs	2.0
4.5 - 9.2	6 Cs	4.0
9.2 - 15.3	NxCs	8.0
15.3 - 18.7	NxCs	15.0
18.7 - 33.2	Cmt	12.1 - 18.7 Cmt

Hole Completion and Monitoring Data.—Data to be shown in this section of the left-hand column includes hole completion, surveys, water levels, drilling rates or time, and reason for hole termination.

1. Borehole Survey Data.—Include if obtained.

Example of survey data:

Depth (ft)	Bearing	Plunge
59		90°
79	S. 72° W.	90°
99	S. 75° W.	89°
119	S. 72° W.	89°
Avg.	S. 72° W.	89°

2. Water Level Data.—Note location, water quantities, and pressures from artesian flows. Water levels or flows should be recorded during hole advancement when possible, but definitely should be recorded at completion of the hole and periodically thereafter. It may be advantageous to leave space or provide a note to refer the user to additional readings provided elsewhere on the log for subsequent measurements. Computer generated logs allow convenient updating of water levels long after the hole is completed.

Examples of drill hole logs illustrate optional format and subsequent readings. Examples of how to record data are:

Date 1981	Hole depth (ft)	Depth to water (ft)
11-02	25.0	6.0
Bailed 100 gal:		
Level before		6.0
Level after		21.0

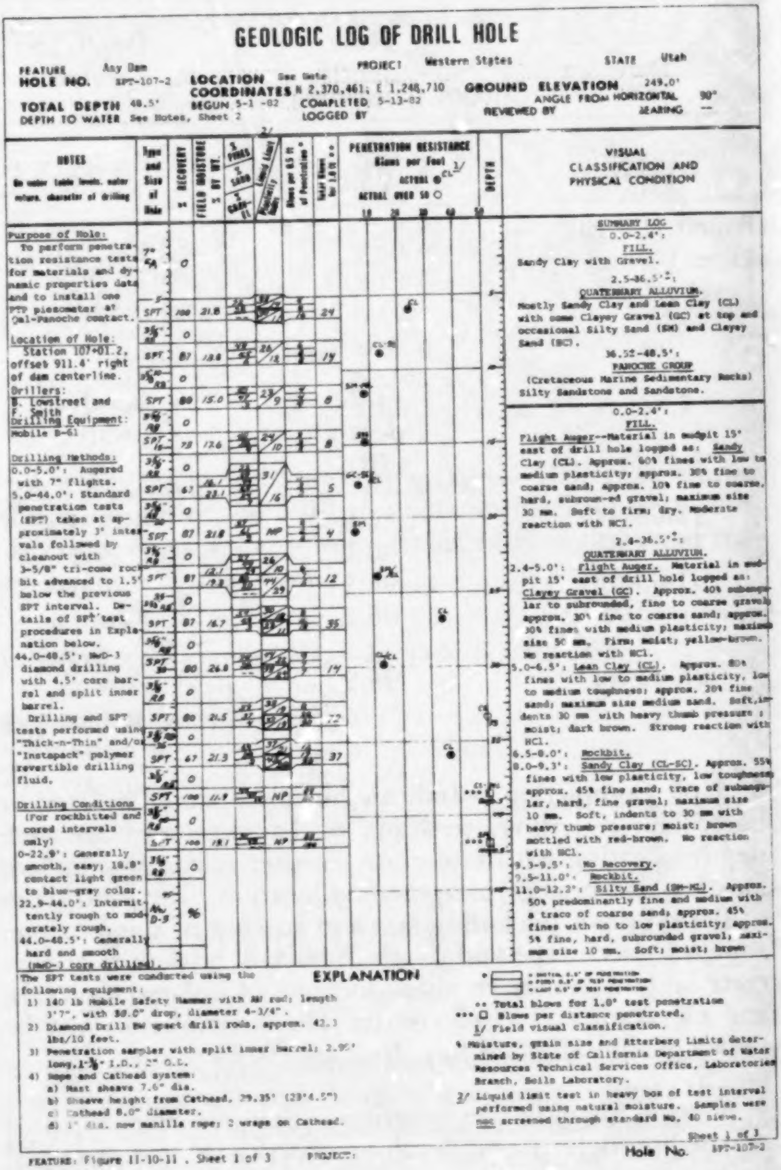
or:

Date	Hole depth (ft)	Depth to water (ft)
11-03-81	25.0	15.0
11-04-81	40.0	29.0
01-05-82	95.2	7.0
01-15-82	95.2	Flowing 25 gal/min
02-03-82	95.2	Flowing 5 gal/min at 5 lb/in^2

3. Hole Completion.—Indicate how hole was completed or backfilled; if jetting, washing, or bailing was employed; depth of casing left in hole, or whether casing was pulled; location and type of piezometers; location, sizes, and types of slotted pipes (including size and spacing of slots) or piezometer risers; type and depth of backfill or depths of concrete and/or bentonite plugs; location of isolated intervals; and elevation at top of riser(s). Hole completion can be shown graphically (see figs. 10-5 and 10-6).

4. Reason for Hole Termination.—State whether the hole reached predetermined depth or reason why it was stopped before reaching predetermined depth.

5. Drilling Time.—Total time, setup time, drilling time, and downtime should be recorded on drillers' daily sheets and is useful data to record on the drill log. Records such



GEOLOGIC LOG OF DRILL HOLE

FEATURE Any Dam
PROJECT Western States
STATE Utah
HOLE NO. SPT-107-2
LOCATION See Note
COORDINATES N 2,370,461; E 1,248,710
GROUND ELEVATION 249.0'
ANGLE FROM HORIZONTAL 90°
TOTAL DEPTH 48.5'
BEGUN 5-1-82
COMPLETED 5-13-82
REVIEWED BY
BEARING —
DEPTH TO WATER See Notes, Sheet 2
LOGGED BY

NOTES
On water table levels, water return, character of drilling

Purpose of Hole:
To perform penetration resistance tests for materials and dynamic properties data and to install one PTP piezometer at Qal-Panoche contact.

Location of Hole:
Station 107+01.2, offset 911.4' right of dam centerline.

Drillers:
B. Lowstreet and F. Smith

Drilling Equipment:
Mobile B-61

Drilling Methods:
0.0-5.0': Augered with 7" flights.
5.0-44.0': Standard penetration tests (SPT) taken at approximately 3' intervals followed by cleanout with 3-5/8" tri-cone rock bit advanced to 1.5' below the previous SPT interval. Details of SPT test procedures in Explanation below.
44.0-48.5': NWD-3 diamond drilling with 4.5' core barrel and split inner barrel.
Drilling and SPT tests performed using "Thick-n-Thin" and/or "Instapack" polymer revertible drilling fluid.

Drilling Conditions
(For rockbitted and cored intervals only)
0-22.9': Generally smooth, easy; 18.8' contact light green to blue-grey color.
22.9-44.0': Intermittently rough to moderately rough.
44.0-48.5': Generally hard and smooth (NWD-3 core drilling).

VISUAL CLASSIFICATION AND PHYSICAL CONDITION

SUMMARY LOG
0.0-2.4':
FILL.
Sandy Clay with Gravel.

2.5-36.5'*:
QUATERNARY ALLUVIUM.
Mostly Sandy Clay and Lean Clay (CL) with some Clayey Gravel (GC) at top and occasional Silty Sand (SM) and Clayey Sand (SC).

36.52-48.5':
PANOCHE GROUP
(Cretaceous Marine Sedimentary Rocks)
Silty Sandstone and Sandstone.

0.0-2.4':
FILL.
Flight Auger--Material in mudpit 15' east of drill hole logged as: Sandy Clay (CL). Approx. 60% fines with low to medium plasticity; approx. 30% fine to coarse sand; approx. 10% fine to coarse, hard, subroun-ed gravel; maximum size 30 mm. Soft to firm; dry. Moderate reaction with HCl.

2.4-36.5'*:
QUATERNARY ALLUVIUM.
2.4-5.0': Flight Auger. Material in mudpit 15' east of drill hole logged as: Clayey Gravel (GC). Approx. 40% subangular to subrounded, fine to coarse gravel; approx. 30% fine to coarse sand; approx. 30% fines with medium plasticity; maximum size 50 mm. Firm; moist; yellow-brown. No reaction with HCl.
5.0-6.5': Lean Clay (CL). Approx. 80% fines with low to medium plasticity, low to medium toughness; approx. 20% fine sand; maximum size medium sand. Soft, indents 30 mm with heavy thumb pressure; moist; dark brown. Strong reaction with HCl.
6.5-8.0': Rockbit.
8.0-9.3': Sandy Clay (CL-SC). Approx. 55% fines with low plasticity, low toughness; approx. 45% fine sand; trace of subangular, hard, fine gravel; maximum size 10 mm. Soft, indents to 30 mm with heavy thumb pressure; moist; brown mottled with red-brown. No reaction with HCl.
9.3-9.5': No Recovery.
9.5-11.0': Rockbit.
11.0-12.2': Silty Sand (SM-ML). Approx. 50% predominantly fine and medium with a trace of coarse sand; approx. 45% fines with no to low plasticity; approx. 5% fine, hard, subrounded gravel; maximum size 10 mm. Soft; moist; brown

EXPLANATION

The SPT tests were conducted using the following equipment:
1) 140 lb Mobile Safety Hammer with AW rod; length 3'7", with 30.0" drop, diameter 4-3/4".
2) Diamond Drill BW upset drill rods, approx. 42.3 lbs/10 feet.
3) Penetration sampler with split inner barrel; 2.95' long, 1-3/8" I.D., 2" O.D.
4) Rope and Cathead system:
a) Mast sheave 7.6" dia.
b) Sheave height from Cathead, 29.35' (29'4.5")
c) Cathead 8.0" diameter.
d) 1" dia. new manilla rope; 2 wraps on Cathead.

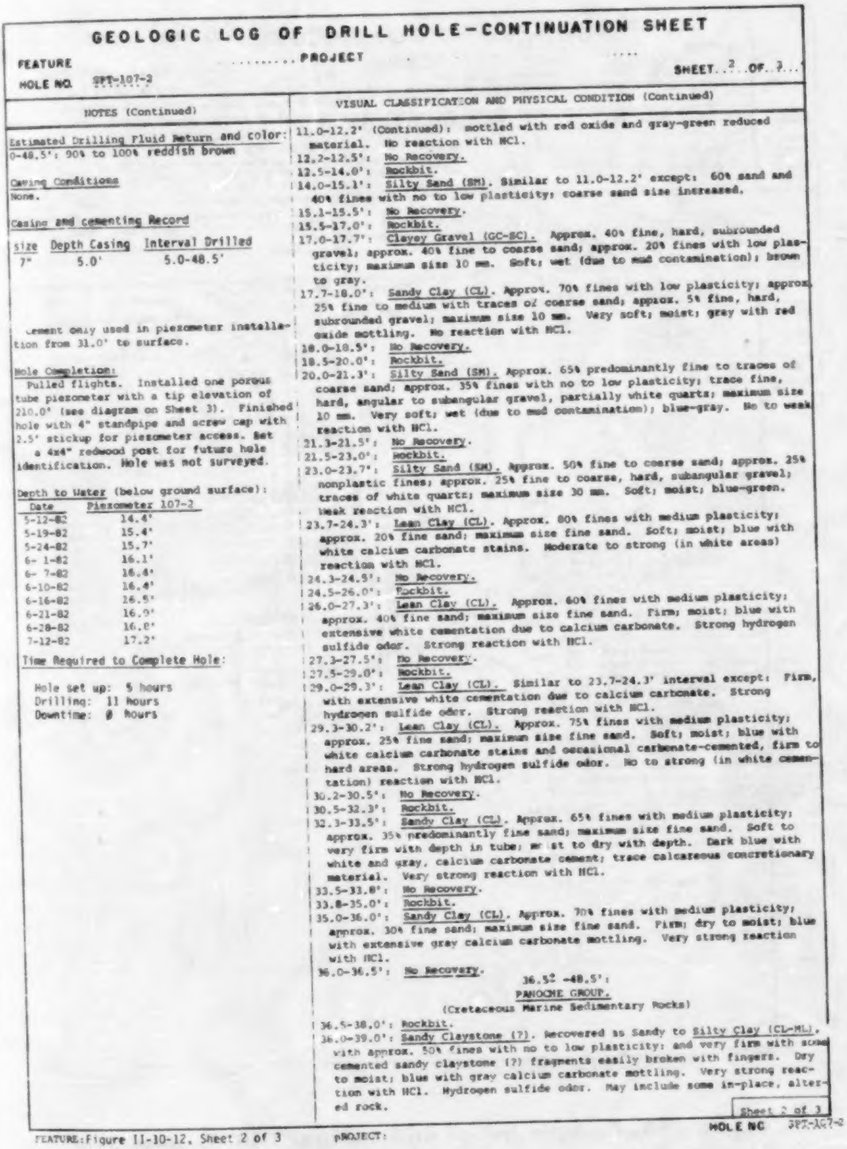
o Initial 0.5' of penetration
o First 0.5' of test penetration
o Last 0.5' of test penetration

•• Total blows for 1.0' test penetration
••• ☐ Blows per distance penetrated.
1/ Field visual classification.
* Moisture, grain size and Atterberg Limits determined by State of California Department of Water Resources Technical Services Office, Laboratories Branch, Soils Laboratory.
2/ Liquid limit test in heavy box of test interval performed using natural moisture. Samples were not screened through standard No. 40 sieve.

Sheet 1 of 3

FEATURE: Figure 11-10-11 . Sheet 1 of 3
PROJECT:
Hole No. SPT-107-2

Figure 10-5. Geologic log of drill hole, SPT-107-2, sheet 1 of 3.



GEOLOGIC LOG OF DRILL HOLE–CONTINUATION SHEET

FEATURE ....PROJECT .....

SHEET..2..OF..3...

HOLE NO. SPT-107-2

NOTES (Continued)

Estimated Drilling Fluid Return and color:
0-48.5': 90% to 100% reddish brown

Casing Conditions
None.

Casing and cementing Record

size	Depth Casing	Interval Drilled
7"	5.0'	5.0-48.5'

Cement only used in piezometer installation from 31.0' to surface.

Hole Completion:
Pulled flights. Installed one porous tube piezometer with a tip elevation of 210.0' (see diagram on Sheet 3). Finished hole with 4" standpipe and screw cap with 2.5' stickup for piezometer access. Set a 4x4" redwood post for future hole identification. Hole was not surveyed.

Depth to Water (below ground surface):

Date	Piezometer 107-2
5-12-82	14.4'
5-19-82	15.4'
5-24-82	15.7'
6- 1-82	16.1'
6- 7-82	16.4'
6-10-82	16.4'
6-16-82	16.5'
6-21-82	16.9'
6-28-82	16.8'
7-12-82	17.2'

Time Required to Complete Hole:

Hole set up: 5 hours
Drilling: 11 hours
Downtime: 0 hours

VISUAL CLASSIFICATION AND PHYSICAL CONDITION (Continued)

11.0-12.2' (Continued): mottled with red oxide and gray-green reduced material. No reaction with HCl.

12.2-12.5': No Recovery.

12.5-14.0': Rockbit.

14.0-15.1': Silty Sand (SM). Similar to 11.0-12.2' except: 60% sand and 40% fines with no to low plasticity; coarse sand size increased.

15.1-15.5': No Recovery.

15.5-17.0': Rockbit.

17.0-17.7': Clayey Gravel (GC-SC). Approx. 40% fine, hard, subrounded gravel; approx. 40% fine to coarse sand; approx. 20% fines with low plasticity; maximum size 10 mm. Soft; wet (due to mud contamination); brown to gray.

17.7-18.0': Sandy Clay (CL). Approx. 70% fines with low plasticity; approx. 25% fine to medium with traces of coarse sand; approx. 5% fine, hard, subrounded gravel; maximum size 10 mm. Very soft; moist; gray with red oxide mottling. No reaction with HCl.

18.0-18.5': No Recovery.

18.5-20.0': Rockbit.

20.0-21.3': Silty Sand (SM). Approx. 65% predominantly fine to traces of coarse sand; approx. 35% fines with no to low plasticity; trace fine, hard, angular to subangular gravel, partially white quartz; maximum size 10 mm. Very soft; wet (due to mud contamination); blue-gray. No to weak reaction with HCl.

21.3-21.5': No Recovery.

21.5-23.0': Rockbit.

23.0-23.7': Silty Sand (SM). Approx. 50% fine to coarse sand; approx. 25% nonplastic fines; approx. 25% fine to coarse, hard, subangular gravel; traces of white quartz; maximum size 30 mm. Soft; moist; blue-green. Weak reaction with HCl.

23.7-24.3': Lean Clay (CL). Approx. 80% fines with medium plasticity; approx. 20% fine sand; maximum size fine sand. Soft; moist; blue with white calcium carbonate stains. Moderate to strong (in white areas) reaction with HCl.

24.3-24.5': No Recovery.

24.5-26.0': Rockbit.

26.0-27.3': Lean Clay (CL). Approx. 60% fines with medium plasticity; approx. 40% fine sand; maximum size fine sand. Firm; moist; blue with extensive white cementation due to calcium carbonate. Strong hydrogen sulfide odor. Strong reaction with HCl.

27.3-27.5': No Recovery.

27.5-29.0': Rockbit.

29.0-29.3': Lean Clay (CL). Similar to 23.7-24.3' interval except: Firm, with extensive white cementation due to calcium carbonate. Strong hydrogen sulfide odor. Strong reaction with HCl.

29.3-30.2': Lean Clay (CL). Approx. 75% fines with medium plasticity; approx. 25% fine sand; maximum size fine sand. Soft; moist; blue with white calcium carbonate stains and occasional carbonate-cemented, firm to hard areas. Strong hydrogen sulfide odor. No to strong (in white cementation) reaction with HCl.

30.2-30.5': No Recovery.

30.5-32.3': Rockbit.

32.3-33.5': Sandy Clay (CL). Approx. 65% fines with medium plasticity; approx. 35% predominantly fine sand; maximum size fine sand. Soft to very firm with depth in tube; moist to dry with depth. Dark blue with white and gray, calcium carbonate cement; trace calcareous concretionary material. Very strong reaction with HCl.

33.5-33.8': No Recovery.

33.8-35.0': Rockbit.

35.0-36.0': Sandy Clay (CL). Approx. 70% fines with medium plasticity; approx. 30% fine sand; maximum size fine sand. Firm; dry to moist; blue with extensive gray calcium carbonate mottling. Very strong reaction with HCl.

36.0-36.5': No Recovery.

36.5± -48.5':
PANOCHE GROUP.
(Cretaceous Marine Sedimentary Rocks)

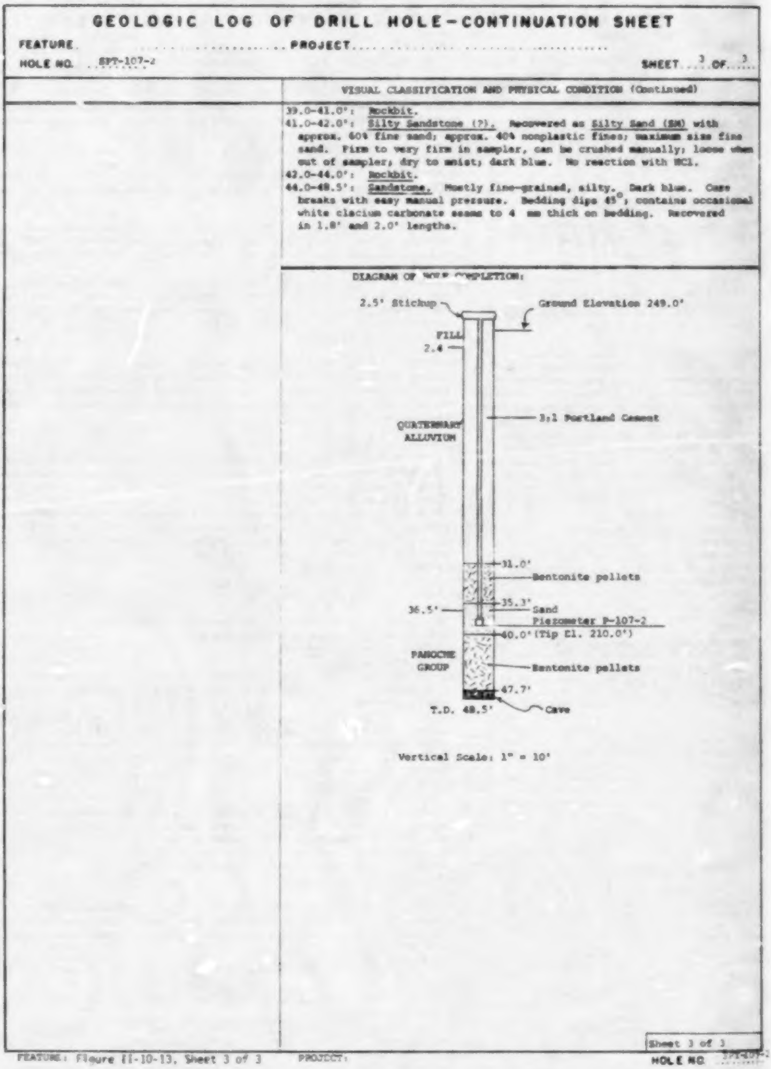
36.5-38.0': Rockbit.

36.0-39.0': Sandy Claystone (?). Recovered as Sandy to Silty Clay (CL-ML), with approx. 50% fines with no to low plasticity; and very firm with some cemented sandy claystone (?) fragments easily broken with fingers. Dry to moist; blue with gray calcium carbonate mottling. Very strong reaction with HCl. Hydrogen sulfide odor. May include some in-place, altered rock.

Sheet 2 of 3

FEATURE: Figure II-10-12, Sheet 2 of 3 PROJECT: HOLE NO SPT-107-2

Figure 10-5. Geologic log of drill hole, SPT-107-2, sheet 2 of 3. (continued)



GEOLOGIC LOG OF DRILL HOLE–CONTINUATION SHEET

FEATURE .... PROJECT ....

HOLE NO. SPT-107-2 SHEET 3 OF 3

VISUAL CLASSIFICATION AND PHYSICAL CONDITION (Continued)

39.0-41.0': Rockbit.

41.0-42.0': Silty Sandstone (?). Recovered as Silty Sand (SM) with approx. 60% fine sand; approx. 40% nonplastic fines; maximum size fine sand. Firm to very firm in sampler, can be crushed manually; loose when out of sampler; dry to moist; dark blue. No reaction with HCl.

42.0-44.0': Rockbit.

44.0-48.5': Sandstone. Mostly fine-grained, silty. Dark blue. Core breaks with easy manual pressure. Bedding dips 45°; contains occasional white clacium carbonate seams to 4 mm thick on bedding. Recovered in 1.8' and 2.0' lengths.

DIAGRAM OF HOLE COMPLETION:

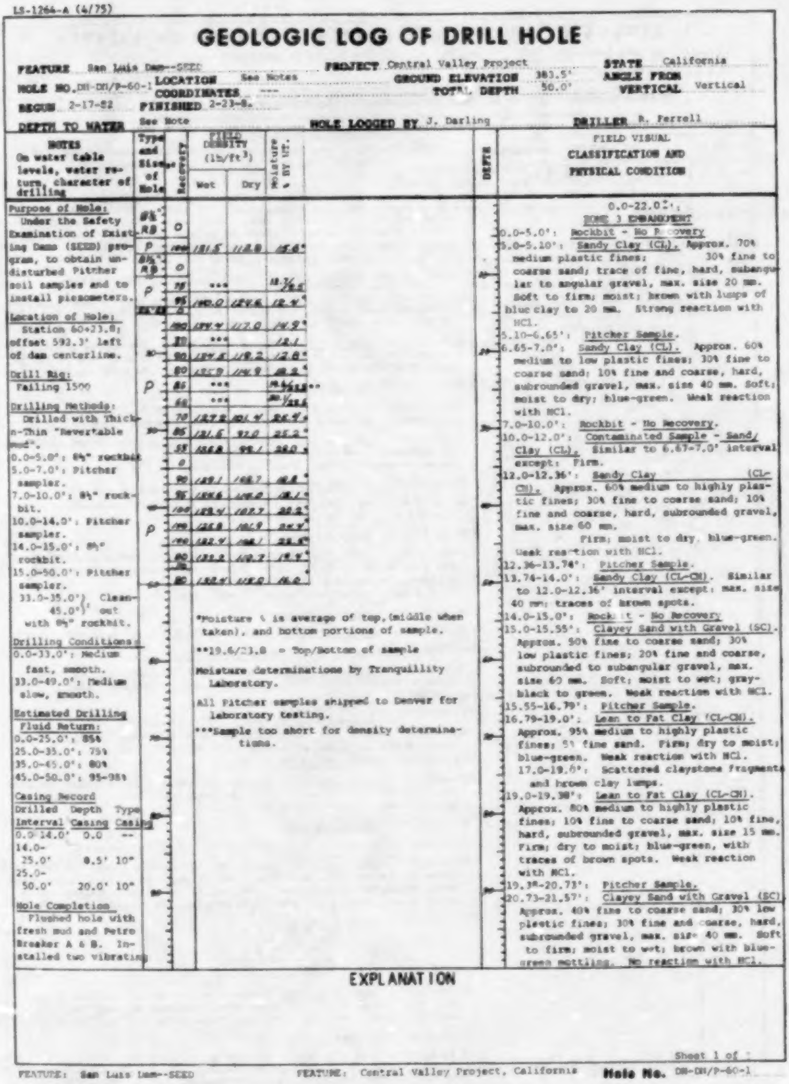
Vertical Scale: 1" = 10'

Sheet 3 of 3

FEATURE: Figure II-10-13, Sheet 3 of 3 PROJECT:

HOLE NO. SPT-107-2

Figure 10-5. Geologic log of drill hole, SPT-107-2, sheet 3 of 3. (continued)



LS-1264-A (4/75)

GEOLOGIC LOG OF DRILL HOLE

FEATURE San Luis Dam--SEED **PROJECT** Central Valley Project **STATE** California
HOLE NO. DH-DN/P-60-1 **LOCATION COORDINATES** See Notes --- **GROUND ELEVATION** 383.5' **TOTAL DEPTH** 50.0' **ANGLE FROM VERTICAL** Vertical
BEGUN 2-17-82 **FINISHED** 2-23-8.
DEPTH TO WATER See Note **HOLE LOGGED BY** J. Darling **DRILLER** R. Ferrell

NOTES On water table levels, water return, character of drilling

Purpose of Hole:
Under the Safety Examination of Existing Dams (SEED) program, to obtain undisturbed Pitcher soil samples and to install piezometers.

Location of Hole:
Station 60+23.8; offset 592.3' left of dam centerline.

Drill Rig:
Failing 1500

Drilling Methods:
Drilled with Thick-n-Thin "Revertable Mud".
0.0-5.0': 8¾" rockbit
5.0-7.0': Pitcher sampler.
7.0-10.0': 8¾" rockbit.
10.0-14.0': Pitcher sampler.
14.0-15.0': 8¾" rockbit.
15.0-50.0': Pitcher sampler.
33.0-35.0'}, 45.0'}: Clean-out with 8¾" rockbit.

Drilling Conditions:
0.0-33.0': Medium fast, smooth.
33.0-49.0': Medium slow, smooth.

Estimated Drilling Fluid Return:
0.0-25.0': 85%
25.0-35.0': 75%
35.0-45.0': 80%
45.0-50.0': 95-98%

Casing Record

Drilled Interval	Depth Casing	Type Casing
0.0-14.0'	0.0	--
14.0-25.0'	8.5'	10"
25.0-50.0'	20.0'	10"

Hole Completion
Flushed hole with fresh mud and Petro Breaker A & B. Installed two vibrating

Type and Size of Hole	Recovery	Field Density (lb/ft³) Wet	Field Density (lb/ft³) Dry	Moisture % DY WT.
8¾" RB	0			
P	100	131.5	112.8	15.6*
8¾" RB	0			
P	75	***		18.7/23.5
	95	140.0	124.6	12.4*
[illegible]	0			
P	100	129.4	117.0	14.9*
	88	***		12.1
	90	134.5	119.2	12.8*
	80	135.9	114.9	18.2*
	85	***		19.6/23.8**
	66	***		20.4/23.6
	70	127.2	101.4	25.4*
	85	121.6	97.0	25.2*
	55	126.8	98.1	28.0*
	0			
	90	129.1	108.7	18.8*
	95	128.6	110.0	18.1*
	100	129.4	107.7	20.2*
	100	126.8	101.9	24.4*
	100	132.4	108.1	22.5*
	80	131.2	110.7	18.4*
	80	132.4	112.0	18.2*

*Moisture % is average of top, (middle when taken), and bottom portions of sample.

**19.6/23.8 = Top/Bottom of sample

Moisture determinations by Tranquillity Laboratory.

All Pitcher samples shipped to Denver for laboratory testing.

***Sample too short for density determinations.

DEPTH

FIELD VISUAL CLASSIFICATION AND PHYSICAL CONDITION

0.0-22.0':
ZONE 3 EMBANKMENT

0.0-5.0': Rockbit - No Recovery

5.0-5.10': Sandy Clay (CL). Approx. 70% medium plastic fines; 30% fine to coarse sand; trace of fine, hard, subangular to angular gravel, max. size 20 mm. Soft to firm; moist; brown with lumps of blue clay to 20 mm. Strong reaction with HCl.

5.10-6.65': Pitcher Sample.

6.65-7.0': Sandy Clay (CL). Approx. 60% medium to low plastic fines; 30% fine to coarse sand; 10% fine and coarse, hard, subrounded gravel, max. size 40 mm. Soft; moist to dry; blue-green. Weak reaction with HCl.

7.0-10.0': Rockbit - No Recovery.

10.0-12.0': Contaminated Sample - Sandy Clay (CL). Similar to 6.67-7.0' interval except: Firm.

12.0-12.36': Sandy Clay (CL-CH). Approx. 60% medium to highly plastic fines; 30% fine to coarse sand; 10% fine and coarse, hard, subrounded gravel, max. size 60 mm. Firm; moist to dry, blue-green. Weak reaction with HCl.

12.36-13.74': Pitcher Sample.

13.74-14.0': Sandy Clay (CL-CH). Similar to 12.0-12.36' interval except: max. size 40 mm; traces of brown spots.

14.0-15.0': Rockbit - No Recovery.

15.0-15.55': Clayey Sand with Gravel (SC). Approx. 50% fine to coarse sand; 30% low plastic fines; 20% fine and coarse, subrounded to subangular gravel, max. size 60 mm. Soft; moist to wet; gray-black to green. Weak reaction with HCl.

15.55-16.79': Pitcher Sample.

16.79-19.0': Lean to Fat Clay (CL-CH). Approx. 95% medium to highly plastic fines; 5% fine sand. Firm; dry to moist; blue-green. Weak reaction with HCl.
17.0-19.0': Scattered claystone fragments and brown clay lumps.

19.0-19.38': Lean to Fat Clay (CL-CH). Approx. 80% medium to highly plastic fines; 10% fine to coarse sand; 10% fine, hard, subrounded gravel, max. size 15 mm. Firm; dry to moist; blue-green, with traces of brown spots. Weak reaction with HCl.

19.38-20.73': Pitcher Sample.

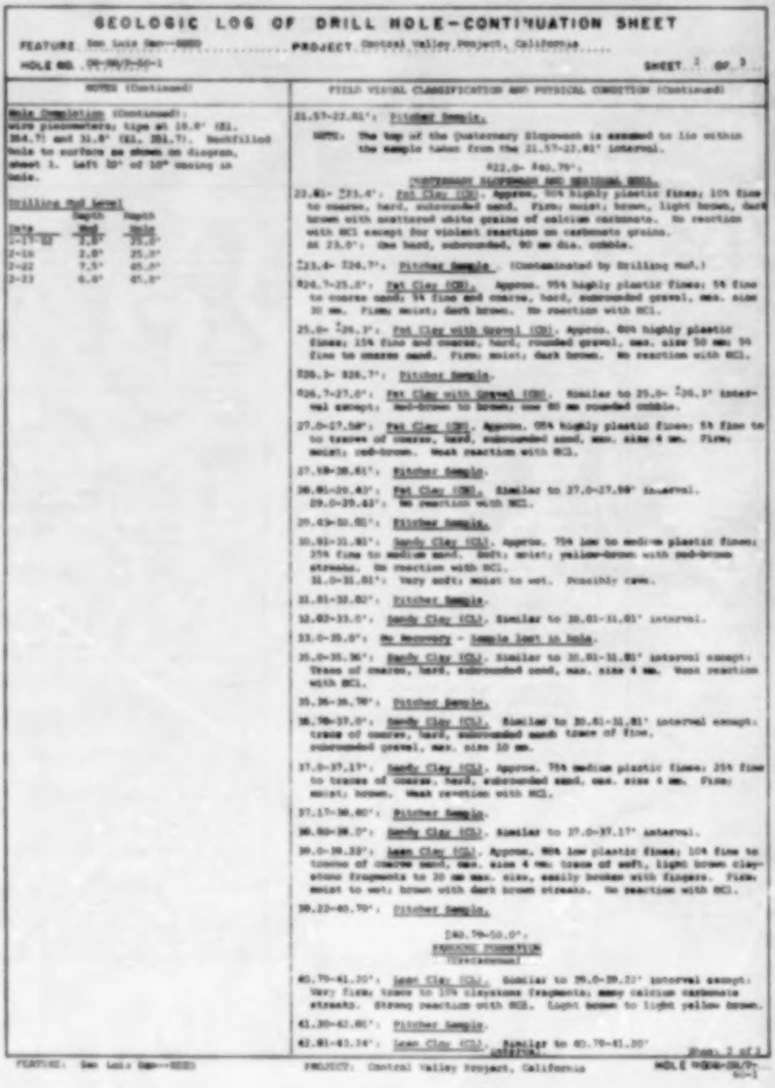
20.73-21.57': Clayey Sand with Gravel (SC). Approx. 40% fine to coarse sand; 30% low plastic fines; 30% fine and coarse, hard, subrounded gravel, max. size 40 mm. Soft to firm; moist to wet; brown with blue-green mottling. No reaction with HCl.

EXPLANATION

Sheet 1 of 3

FEATURE: San Luis Dam--SEED FEATURE: Central Valley Project, California **Hole No.** DH-DN/P-60-1

Figure 10-6. Drill hole log, DH-DN/P-60-1, sheet 1 of 3.



GEOLOGIC LOG OF DRILL HOLE—CONTINUATION SHEET

FEATURE [illegible] PROJECT Central Valley Project, California

HOLE NO. DH-DN/P-60-1 SHEET 2 OF 3

NOTES (Continued)

Hole Completion (Continued): wire piezometers; tips at 10.0' (El. 354.7) and 31.0' (El. 351.7). Backfilled hole to surface as shown on diagram, sheet 1. Left 10' of 10" casing in hole.

Drilling Mud Level

Date	Depth Mud	Depth Hole
2-17-[illegible]	2.0'	25.0'
2-18	2.0'	25.0'
2-22	7.5'	45.0'
2-23	6.0'	41.0'

FIELD VISUAL CLASSIFICATION AND PHYSICAL CONDITION (Continued)

21.57-22.01': Pitcher Sample.

NOTE: The top of the Quaternary Slopewash is assumed to lie within the sample taken from the 21.57-22.01' interval.

±22.0-±40.70':
QUATERNARY SLOPEWASH AND RESIDUAL SOIL.

22.01-±23.4': Fat Clay (CH). Approx. 90% highly plastic fines; 10% fine to coarse, hard, subrounded sand. Firm; moist; brown, light brown, dark brown with scattered white grains of calcium carbonate. No reaction with HCl except for violent reaction on carbonate grains.
At 23.0': One hard, subrounded, 90 mm dia. cobble.

±23.4-±24.7': Pitcher Sample. (Contaminated by Drilling Mud.)

±24.7-25.0': Fat Clay (CH). Approx. 95% highly plastic fines; 5% fine to coarse sand; 5% fine and coarse, hard, subrounded gravel, max. size 30 mm. Firm; moist; dark brown. No reaction with HCl.

25.0-±26.3': Fat Clay with Gravel (CH). Approx. 80% highly plastic fines; 15% fine and coarse, hard, rounded gravel, max. size 50 mm; 5% fine to coarse sand. Firm; moist; dark brown. No reaction with HCl.

±26.3-±26.7': Pitcher Sample.

±26.7-27.0': Fat Clay with Gravel (CH). Similar to 25.0-±26.3' interval except: Red-brown to brown; one 80 mm rounded cobble.

27.0-27.58': Fat Clay (CH). Approx. 95% highly plastic fines; 5% fine to to traces of coarse, hard, subrounded sand, max. size 4 mm. Firm; moist; red-brown. Weak reaction with HCl.

27.58-28.01': Pitcher Sample.

28.01-29.43': Fat Clay (CH). Similar to 27.0-27.58' interval.
29.0-29.43': No reaction with HCl.

29.43-30.01': Pitcher Sample.

30.01-31.01': Sandy Clay (CL). Approx. 75% low to medium plastic fines; 25% fine to medium sand. Soft; moist; yellow-brown with red-brown streaks. No reaction with HCl.
31.0-31.01': Very soft; moist to wet. Possibly cave.

31.01-32.02': Pitcher Sample.

32.02-33.0': Sandy Clay (CL). Similar to 30.01-31.01' interval.

33.0-35.0': No Recovery - Sample lost in hole.

35.0-35.36': Sandy Clay (CL). Similar to 30.01-31.01' interval except: Trace of coarse, hard, subrounded sand, max. size 4 mm. Weak reaction with HCl.

35.36-36.70': Pitcher Sample.

36.70-37.0': Sandy Clay (CL). Similar to 30.01-31.01' interval except: trace of coarse, hard, subrounded sand; trace of fine, subrounded gravel, max. size 10 mm.

37.0-37.17': Sandy Clay (CL). Approx. 75% medium plastic fines; 25% fine to traces of coarse, hard, subrounded sand, max. size 4 mm. Firm; moist; brown. Weak reaction with HCl.

37.17-38.60': Pitcher Sample.

38.60-39.0': Sandy Clay (CL). Similar to 37.0-37.17' interval.

39.0-39.22': Lean Clay (CL). Approx. 90% low plastic fines; 10% fine to traces of coarse sand, max. size 4 mm; trace of soft, light brown claystone fragments to 20 mm max. size, easily broken with fingers. Firm; moist to wet; brown with dark brown streaks. No reaction with HCl.

39.22-40.70': Pitcher Sample.

±40.70-50.0':
PANOCHE FORMATION
(Cretaceous)

40.70-41.20': Lean Clay (CL). Similar to 39.0-39.22' interval except: Very firm; trace to 15% claystone fragments; many calcium carbonate streaks. Strong reaction with HCl. Light brown to light yellow brown.

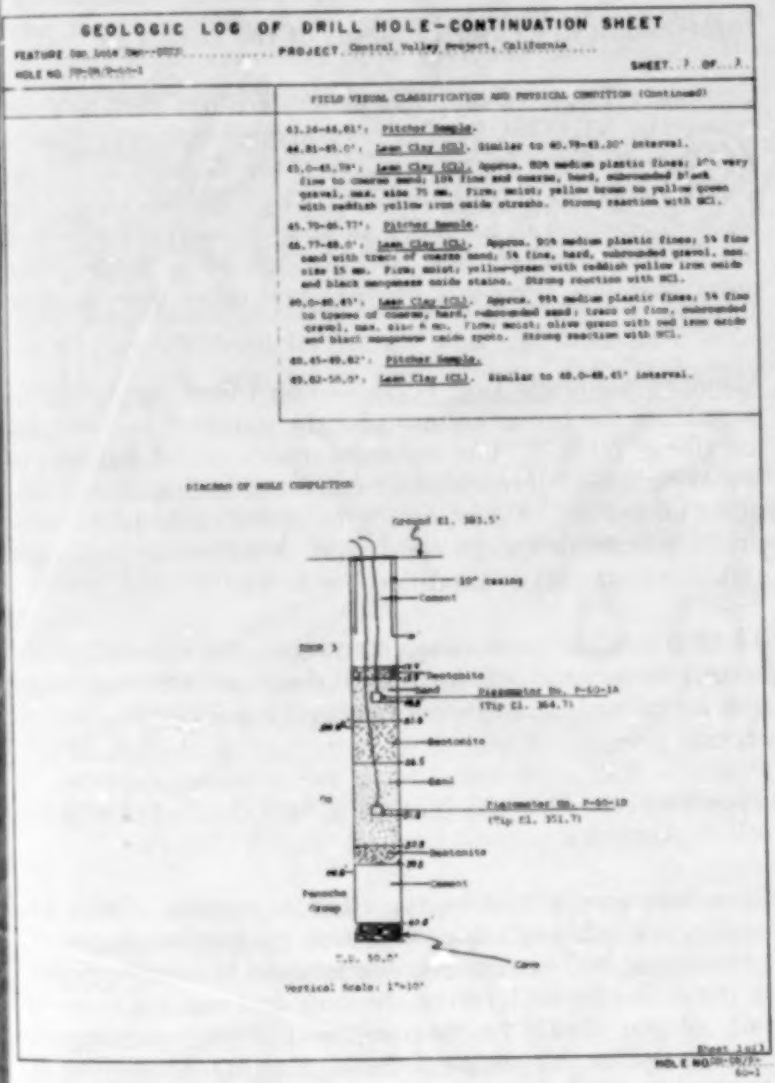
41.20-42.01': Pitcher Sample.

42.01-43.34': Lean Clay (CL). Similar to 40.70-41.20' interval.

Sheet 2 of 3

FEATURE: [illegible] PROJECT: Central Valley Project, California HOLE NO. DH-DN/P-60-1

Figure 10-6. Drill hole log, DH-DN/P-60-1, sheet 2 of 3. (continued)



GEOLOGIC LOG OF DRILL HOLE–CONTINUATION SHEET

FEATURE San Luis Dam–[illegible] PROJECT Central Valley Project, California

HOLE NO. DH-DN/P-60-1 SHEET 3 OF 3

FIELD VISUAL CLASSIFICATION AND PHYSICAL CONDITION (Continued)

43.24-44.81': Pitcher Sample.

44.81-45.0': Lean Clay (CL). Similar to 40.78-43.20' interval.

45.0-45.70': Lean Clay (CL). Approx. 80% medium plastic fines; 10% very fine to coarse sand; 10% fine and coarse, hard, subrounded black gravel, max. size 75 mm. Firm; moist; yellow brown to yellow green with reddish yellow iron oxide streaks. Strong reaction with HCl.

45.70-46.77': Pitcher Sample.

46.77-48.0': Lean Clay (CL). Approx. 90% medium plastic fines; 5% fine sand with trace of coarse sand; 5% fine, hard, subrounded gravel, max. size 15 mm. Firm; moist; yellow-green with reddish yellow iron oxide and black manganese oxide stains. Strong reaction with HCl.

48.0-48.45': Lean Clay (CL). Approx. 95% medium plastic fines; 5% fine to traces of coarse, hard, subrounded sand; trace of fine, subrounded gravel, max. size 6 mm. Firm; moist; olive green with red iron oxide and black manganese oxide spots. Strong reaction with HCl.

48.45-49.82': Pitcher Sample.

49.82-50.0': Lean Clay (CL). Similar to 48.0-48.45' interval.

DIAGRAM OF HOLE COMPLETION

Vertical Scale: 1"=10'

Sheet 3 of 3
HOLE NO. DH-DN/P-60-1

Figure 10-6. Drill hole log, DH-DN/P-60-1, sheet 3 of 3. (continued)

as these are essential for determining exploration program costs.

Information in Center Columns of the Drill Log

Computer Logs.—Computer-generated logs such as those created by NGEOSUB, offer several options for the content and format of the center portion of the log such as permeability, penetration resistance, or rock properties which have some differences in format. Examples of each are provided but not discussed (see figs. 10-2 through 10-5). Appropriate users' manuals, the *Earth Manual*, and other directives are available.

Standard Geologic Log Form.—The following discussion pertains to the center columns for the standard Reclamation log (form 7-1337). The columns shown on all figures are self-explanatory. The columns can be modified or new columns added to the existing log form for recording appropriate indexes or special conditions. A following paragraph contains examples of modified log forms.

The Percolation Tests (water-pressure tests) column should record the general information of the tests. Additional data may be recorded on "water testing" log forms or drillers' reports.

Type and Size of Hole, Elevation, and Depth columns are self-explanatory.

Core Recovery should be recorded in percent of recovery by run, and, although desirable, does not necessarily require a visual graph. The core recovery should be noted carefully by the driller for each run on the daily drill reports; however, this column should be the record of those measurements determined by the geologist during logging. Measuring the core while in the inner tube or sampler, if possible, will produce the most accurate recovery records.

A Hole Completion column may be added which graphically portrays how the hole was completed. If used, an explanation of the graphic symbols should be provided on the log form.

RQD (Rock Quality Designation) should be reported by core run. This column is considered necessary for all underground structures and is recommended for most logs. Today, most contractors are interested in RQD as a measure of blasting performance, rippability, and stability. RQD is described and explained in Chapter 5.

A Lithologic Log or graphic column is helpful to quickly visualize the geologic conditions. Appropriate symbols may be used for correlation of units, shear zones, water levels, weathering, and fracturing (see figs. 10-1 through 10-3).

The Samples and Testing column should include locations of samples obtained for testing and can later have actual sample results inserted in the column, if the column is enlarged.

Modifications to Standard Log Form.—Modifications or adaptations of the center columns are permissible and in some instances encouraged. Modifications that have received favorable comments include:

1. The use of a continuation sheet for longer drill logs saves time, is easier to type, and results in lower printing costs. The sheets may have only one column to continue the right-hand narrative, or it may be divided into two or more columns. See sheet 2 and 3 for drill hole SPT-107-2, figure 10-5, for an example; sheet 3 of 3 for drill hole DH-DN/P-60-1, figure 10-6.

2. The center column may be modified to portray additional data such as hole completion, various indexes, alphanumeric descriptors, or labortory test data.

Standard Penetration Test Hole SPT-107-2, figure 10-5, is a modified penetration resistance log which portrays laboratory test results; this includes a percent gravel/percent sand/percent fines column; and LL (liquid limit)/PI (plasticity index) column, a field moisture column, and other modifications. Drill hole DH-SP-2, figure 10-3, has columns for reporting field density test results, moisture, porosity, percent saturation, percent fines/percent sand, PI/LL, and laboratory classification.

3. Other modifications, one of which also is shown on DH-SP-2, figure 10-3, is a drawing showing the location of the hole in relation to the structure being explored. Diagrams or graphs, such as water levels, may illustrate data better than a column of figures.

Required Data and Descriptions for the Right-Hand "Classification and Physical Condition" Column

General.—An accurate description of recovered core and a technically sound interpretation of non-recovered core are the primary reasons for core logging. The logger must remember that any interpretation, such as a shear, must be based on observed factual data. The interpreted reason for the core loss is given, but usually it is best to define the area of core loss as the interval heading. For example:

> "***99.4. to 101.6: No Recovery. Interpreted to be intensely fractured zone. Drillers reported blocking off, core probably ground up during drilling***."
>
> "***103.4 to 103.7: Open Joint?. Drillers reported 0.3-ft drop of drill rods during drilling and loss of all water. Joint surfaces in core do not match***."
>
> "***0.7 to 11.6: Silty Sand. Poor recovery, only 6.2 ft recovered from interval. Classification based on recovered material and wash samples***."
>
> "***0.9 to 3.2: Rockbitted. No samples recovered***." (Usually this would be subheaded under a previous description, thereby inferring the materials are interpreted to be the same as last recovered).

Descriptions of Surficial Deposits.—Surficial deposits such as slope wash, alluvium, colluvium, and residual soil that are recovered from drill holes are described using USBR 5000 and 5005. If samples cannot be obtained, then descriptive terms of the cuttings, percent return and color of drilling fluid, drilling characteristics, and correlation to surface exposures must be employed. It is always necessary to record what is being described—undisturbed samples, SPT samples, wash samples, cuttings or cores. Descriptors and descriptive criteria for the physical characteristics of soils must conform to the established standards. Chapter 11 provides guidelines to describe soils and surficial deposits.

Extensive surficial deposits usually are described using soil classifications. Where surficial deposits are very shallow and not pertinent to engineering applications for design, where geologic classification such as landslides or talus is preferable, units may be given genetic or stratigraphic terms instead of group names and symbolic. For example, Quaternary basin fill, Recent stream channel despoits, Quaternary colluvium, zone 3 embankment, and random fill may be described generally; or these may be unit headings with group name subheadings. The format is:

1. Group name.—i.e., sandy silt. Field classification in parenthesis if classified, refer to Chapters 3 and 11 for exceptions.

2. Classification descriptions.—Additional descriptors (particle sizes, strengths, consistency, compactness, etc., from the 5000 and 5005 standards descriptive criteria).

3. Moisture.—(dry to wet).

4. Color.—

If cores or disturbed samples are not available, describe as many of above items that can be determined from cuttings, drill water color, drilling characeristics, correlation to surface exposures, etc. Remember that for rockbitted, no recovery, or poor recovery intervals, a classification and group name WILL NOT be assigned as a primary identification.

Description of Rock. Description of rock includes a rock unit name based on general lithologic characteristics followed by data on structural features and physical conditions. Bedrock or lithologic units are to be delineated and identified, not only by general rock types but by any special geological, mineralogical features with engineering significance, or those pertinent to interpretation of the subsurface conditions.

Any information which is characteristic of all of the rock units encountered may be included under the main heading, producing more concise logs. Differences can be described in various subheadings. Rock core is to be described in accordance with descriptors and descriptive criteria presented in Chapters 4 and 5. A suggested format follows:

1. Rock name.—A simple descriptive name, sufficient to provide others with possible engineering properties of the rock type; may include geological age and/or stratigraphic unit name.

2. Lithologic descriptors—(composition/grain sizes/texture/color).—Give a brief mineralogical description. Describe grain shape and size or sizes, and texture using textural adjectives such as vesicular, porphyritic, subschistose. (Do not use sophisticated technical terms such as hypidiomorphic, subidioblastic). Other pertinent descriptions could include porosity, absorption, physical characteristics that assist in correlation studies, and other typical and/or unusual properties. Provide the wet color of fresh and weathered surfaces.

Contacts should be described here also. If they are fractured, sheared, open, or have other significant properties, they should be identified and described under separate subheadings.

3. Bedding/foliation/flow texture.—Provide a description of thickness of bedding, banding, or foliation including the dip or inclination of these features.

4. Weathering/alteration.—Use established descriptors which apply to most of core or individual subheadings. For alteration other than weathering use appropriate descriptors. These may or may not be separate from weathering depending upon rock type and type of alteration. Also, include slaking properties if the material air or water slakes. (Weathering may be used as first or second order headings for some logs.)

5. Hardness.—Use established descriptors.

6. Discontinuities.—These include shears, fractures, and contacts. See the following paragraphs for more detailed discussion of discontinuity descriptions.

a. Description of bedding or foliation joints, such as attitude, spacing, roughness.

b. Description of fracture and other joint attitudes, and spacing, roughness.

c. Fracture density descriptor and lengths of core recovered.

d. Shears and sheared or jointed contacts normally are subheaded and described after the general discussion.

Description of Discontinuities.—Because discontinuities control or significantly influence the behavior of the rock mass, they must be described in detail. Detailed discussions of indexes and of descriptive criteria, descriptors and terminology for describing fractures and shears are provided in Chapter 5.

Fracture Indexes.—There are three accepted indexes and established criteria pertinent for describing, evaluating, and presenting discontinuity data. The indexes are fracture density, fracture frequency, and RQD.

- Fracture Density.—Fracture density is based on spacing of all naturally occurring discontinuities in the recovered core (core recovery lengths). Maximum and minimum lengths and a range or average length of recovered core should be recorded. These fracture spacings always should be described in physical measurements, but descriptive terms relating to these measurements are convenient and aid in communicating characteristics of rock the mass. It is usually helpful to provide a percentage of the types of discontinuities present. A complete description for fracture density might read: "Slightly fractured, recovered core in 1.5- to 4.6-ft lengths, mostly 1.7 ft (25% bedding joints/75% joints)."
- Fracture frequency.—Fractures per base length.
- RQD.—RQD generally should be provided.

Fracture Descriptions.—Fractures or joints should be categorized into sets based on similar orientations, and each set should be described. When possible, each set should be assigned letter and/or number designations, and variations in their physical properties noted by depth intervals. Significant individual joints also may be identified and described. Along with physical measurements, such as spacing and orientation (dip or inclination from core axis) should be information such as composition, thickness, and hardness of fillings or coatings; character of surfaces (smooth or rough); and, when possible, fracture openness. In drill core, the average length between fractures is measured along the centerline of the core for reporting any of the fracture indexes. However, when a set can be distinguished (parallel or subparallel joints) true spacing is measured normal to the fracture surfaces.

3. Description of Shears and Shear Zones.—Shears and shear zones should be described in detail, including data such as percentage of the various components (gouge, rock fragments, associated features such as dikes, and veins) and the relationship of these components to each other. Gouge color, moisture, consistency and composition, and fragment or breccia sizes, shape, surface features, lithology, and strengths are recorded. The depths, dip or inclination, and true thickness, measured normal to the shear or fault contacts, also must be determined if possible, along with healing, strength, and other associated features. A thorough discussion of shears and shear zones is contained in Chapter 5.

Description of Core Loss.—The significance of core loss is often more important than recovered core. Lost core may represent the worst conditions for design concepts or it may be insignificant, resulting from improper drilling techniques or equipment. Core losses, their intervals, and the interpreted reason for the loss should be recorded on the log.

Form of the Written Description.—The written description for physical conditions consists of main headings, indented subheadings, and text which describe the important features of the core. Headings and indented subheadings divide the core into readily distinguishable intervals which are pertinent to an engineering geology study. Assigned unit names should correlate with those unit names used for surface mapping. These headings may describe portions of the core or the entire core, depending on their ability to encompass overall characteristics. Items characteristic of the entire core in one hole may be stated under the major heading; however, in other holes, this same information may have to be broken out into various subheadings because it is not applicable to the entire core. In this discussion, several logs are referenced as examples. These logs do not necessarily reflect the established standards, and each may be deficient in some format or context; they are existing logs which are included as examples of different situations which may be encountered. A discussion of headings follow:

1. Main Headings.—The main heading usually divides surficial deposits from bedrock. However, other methods are also acceptable, for example, the summary log on figure 10–5.

2. First Order Heading.—The first order headings may be based on weathering or lithology. When the initial rock type exhibits more than one weathering break or the lithologic properties are most significant, lithology would be the first order heading. Weathering may be used as first order headings where significant. If a weathering break coincides with a lithologic break, or only one weathering break is present, they may both be included in the main heading. Depending on lithologies present; for example if there is only one rock type, the first order headings may be based on fracturing. The geologist should have the flexibility of determining whether lithology, weathering, or fracturing is to be the subject of the first order heading. In certain circumstances a shear or shear zone or other feature could be given a first order or any lower order heading in order to emphasize its presence or importance. The arrangement which will result in the simplest log is usually the best and should be used. (The following examples are offered for the purpose of explaining use of first, second, and third order headings. These examples are NOT intended to represent examples of complete logs).

An example in which weathering is preferred as the first order heading is:

> 0.0–5.0: SLOPE WASH (main heading).—General description could include the total description of the unit.

5.0–200.0: PALEOZOIC CALAVERAS GROUP (main heading).

5.0–100.3: Moderately Weathered (first order heading based on weathering; descriptions of weathering applicable to all lithologies could be presented here).

5.0– 10.9: Basalt
10.9– 20.1: Limestone
20.1– 50.3: Shale
50.3–100.3: Sandstone
100.3–150.0: Slightly Weathered
100.3–120.2: Sandstone
120.2–150.0: Shale
150.0–200.6: Fresh Shale

An example in which lithology is preferred as the first-order subheading is:

0.0–5.0: SLOPE WASH (main heading).—General description, could include the total description of the unit.

5.0–200.6: PALEOZOIC CALAVERAS GROUP (main heading).—General description applicable to all lithologies.

5.0–100.3: Sandstone (first order heading based on lithology)
5.0– 10.2: Intensely weathered
10.2– 40.1: Moderately weathered
40.1– 80.2: Slightly weathered
80.2–100.3: Fresh
100.3–150.1: Fresh Shale (first order heading which combines weathering and lithology)
150.1–200.6: Fresh Diabase

3. Second Order Heading.—The second order heading and the associated description contains the characteristics of the rock that are unique to an interval that are not described in the main and first order headings. The second order heading usually is based on weathering if the first order heading is based on lithology. If the first order heading is based on weathering, the second order heading would usually be based on lithology. If the fracture density is similar

throughout the interval, it also can be described here; if not, it could be divided into third order headings.

4. Third Order Heading.—The third order heading is usually based on fracture density, subordinate features, variations in lithology, etc. This includes variations of rock quality within a certain lithology due to shears, joints, bedding or foliation joints, or other discontinuities. Core recovery lengths are an indicator of fracture density and should be described under this heading, as in the interval from 87.2 to 101.2 in DH–123 figure 10–1. If the fracture densities are due mainly to prominent joint sets or other discontinuities, the spacing and orientation of individual sets, along with the overall fracture density, should be noted.

5. Additional Indentations.—Additional indentations usually are used to describe additional subordinate features, such as veins or veinlets, variations in lithology, shears, and zones of non- or poor recovery.

In summary, any information consistent throughout a higher order heading, but usually included in a lower one, should be described in the higher order heading to prevent repetition.

Data Required for the Comments/Explanation Block

The comments/explanation block at the bottom of the log form is used for any additional information the logger wishes to include. This may include abbreviation used, gauge height for packer tests, and notes. All logs shall be dated, not just the hole completion date in the heading (code 1), but date it was logged. Revision dates of the log should be noted to ensure that the most recent version of the log can be identified. (Date logged and any subsequent revision dates should be entered in this block). For computerized logs, a date of log entry on the data base, the drill hole log file name, and the NGEOSUB program data base on which the log is stored also could be noted in this block. This allows for easier access to the log files without extensive recordkeeping (or in the case of loss of records).

Method of Reporting Orientation of Planar Discontinuities and Structural Features

True dips can be measured directly in vertical or assumed vertical holes. The dips of planar features in vertical holes are recorded as "dips 60°" or "60° dip" (see Drawing 40-D-6499, fig. 5-9). True dip usually is not known in angle holes and, therefore, orientation is measured from the core axis and called inclination, i.e., "Joints are inclined 45° from the core axis" (fig. 5-9). If dips are known from oriented core or other surveys, dips may be recorded instead of inclination in angle holes. Figure 5-9 demonstrates how misinterpretations can occur; the inclination of a joint in the core from a 45° inclined angle hole can be interpreted as a horizontal joint or as a vertical joint by merely rotating the core.

Core Recovery and Core Losses

Descriptions of core in the Classification and Physical Condition column should describe the recovered core not only by physical measurements (maximum, minimum, and mostly range or average), but should identify and include the interpretation for any core losses, especially if the losses are thought to represent conditions different from the core recovered. Designers and other reviewers of the completed log can incorporate into their design all the factual data that are seen and recorded. What is not seen or reported (core losses) is more difficult to incorporate into the design, and may well be the most significant parameter. Also, core losses and interpretations of the reasons for their loss are significant engineering data that may correlate open joints, soft zones, or shears from boring to boring or from surface features to the subsurface explorations.

Core losses can result from three generalized conditions: inaccurate measurements by the drillers; poor drilling techniques, equipment, and handling; or geologic conditions. The geologist, using the depth of hole, recovered core, observations of the core, and drillers observations is the individual to make interpretations of the core loss. All core should be measured by the logger. If using a split-tube barrel, the core should be measured while in the barrel, and always after core segments are fitted together (using the midpoint of core ends). Unaccountable losses should be reconciled and the location of the loss determined.

Tape checks or rod checks are the most reliable and preferred methods for knowing the exact location of geologic conditions (top of each run is known with certainty) and where losses occur. Whether tape checks are or are not completed, a Drill Core Recovery Log is useful for determining gains and losses for core runs. All core runs should be measured and recorded on the form; gains and losses can be transferred to adjacent runs and cancel out each other during the process of determining where the core loss is located. Inaccurate drillers' measurements, or locations where portions of the previously drilled interval was left in the hole (pulled off, or fell back in and redrilled), can be determined by examining and matching the end and beginning of each core run to see if they fit together or show signs of being redrilled. Gains may be attributed to pulling out the bottom of the hole, mismeasurement, recovering core left in the hole from the previous run, or recovery of expansive, slaking, or stress relieving materials.

Where unaccountable losses occur, the examination of core to determine the reason for that loss is critical. Poor drilling methods (excessive pressure, speed, excessive water discharge from the drill bit, not stopping when fluid return plugs), inaccurate measurements, or geologic conditions responsible for the losses should be ascertained. Core may have spun in the barrel after blocking, an intensely fractured zone may have been ground up, or a shear zone. open joint(s), solution cavity, or joint fillings may have been washed away. Geologic interpretation of the loss is based on examining recovered core and the fractures present in the core. Drill water losses and color, or changes in the drilling conditions noted by the driller, may suggest an interpretation of the core loss. Where losses are judged to occur near a recovered clay "seam," where clay coatings on fracture surfaces, slickensides, and/or breccia and gouge are recorded, the loss may be interpreted as a shear or shear zone. The description should describe fully the factual information—discontinuity surfaces orientation, slickensides, coatings, the presence of gouge and/or fracturing; and the interpretation as a shear should be added. Depending on the confidence of the geologist and based on the observed conditions, the interpretation can be given as "shear," or "shear?," or "probable shear zone." When a portion of a shear zone is interpreted to have been lost during drilling, the no recovery zone should be described as part of the shear and the loss or part of the loss included in the shear's thickness.

Samples

If the geologist selects representative or special samples for laboratory testing, an appropriate space should be left in the core box to replace the sample in case it is not tested, or to ensure that when logs are reviewed, or photographs are taken, recovery is not misleading. This is best accomplished by either filler blocks or a spacer which indicates the top and bottom depths of the sample and a sample number. For N-size cores, a length of 2- by 2-inch (50 by 50 mm) block or other spacers that fill the tray works well. These blocks also should be used to separate core runs. The lettering on the blocks should be easily readable at a distance. Spray painting the blocks white or yellow and lettering them with black waterproof paint will greatly enhance visibility and legibility. The sample interval, and sample number if desired, must be recorded in the Samples for Testing column on the log. A geologist may arbitrarily treat portions of the core as samples to preserve representative samples or protect samples from slaking or other deterioration.

Core Photography

General Photographic Methods

Transmittal of core photographs with the final logs is recommended. They may be included in the data package or as an appendix to the data report. Cores should be photographed while in a fresh condition. Before and after photographs of materials that slake or stress-relieve are recommended. The importance of photographing the core before it has been disturbed in transit and before its moisture content has changed cannot be overemphasized. If proper precautions during transport are followed, and the core is logged in a timely manner, reasonably good photographs can be obtained away from the drilling site. This permits the labeling of core features, if desired.

At least one 8- by 10-inch (200- by 250 mm) black and white photographic print is to be retained as a record copy. The colors of many color prints or negatives either fade or alter over a period of time. A 3- by 5-inch (76 × 127 mm) or 5- by 7-inch (127 × 180 mm) color print of individual core box photographs or an 8- by 10-inch (200 × 250 mm) color print of multiple core box photographs is to be included with the log when submitted in the design data package. A 35-mm color transparency (slide) also has been found to be useful in some design processes and during contract claims. Prints can be made from transparencies.

Many methods are employed by the various field offices for photographing core. Some offices photograph each box of core separately when the box is first filled; others photograph three or more boxes at a time. There are advantages to both procedures: greater detail and photographs depicting fresher conditions are the major advantages of photographing each box individually; when photographing several boxes at a time, transitional features, changes in weathering or fracturing, or large shear zones can be seen in one photograph.

The best method is a combination of the two. The geologist or photographer should take pictures of individual boxes at the drill site and then later the entire hole could be photographed in groups of three or more boxes.

Individual Box Photography

The geologist must box and photograph any portion of core that is in danger of altering or disaggregating because of slaking or "discing" due to stress relief, expansion or shrinkage due to drying because of down time, ends of shifts, or weekends. Under these circumstances, the core should be photographed while it is at or near its natural condition (even if a box is only partially filled).

Each photograph should be taken from approximately the same distance so that the scale of each photograph is identical. The box should fill the frame of the camera, thereby obtaining the highest quality resolution or core detail. The camera should be held as close to normal to the core as possible using a tripod. This can be accomplished by tilting the core box and, if necessary, standing in a pickup bed or other higher vantage point. Most core boxes can be tilted about 70 to 80° before any core is in danger of spilling out, so very little additional height is required. Usually, a simple 2- by 4-foot (0.6- by 1.2-m) wood frame may be constructed at the drill site, or the core box may be leaned against a tool box, pickup tailgate, or other stable object. The Brunton compass can be used to ensure that the box has been placed at a consistent, uniform angle.

All core should be photographed in both a wet and dry condition. In hot or dry weather, the unphotographed boxed core should be covered by moist cloth. When ready to photograph, any dry zones should be touched up using a wet cloth or paintbrush. In extremely hot weather, the boxed core can be sprayer or sprinkled with water. A water hose, garden sprayer, or spray bottle works well for this operation. If this method is used, one must wait for the water to be absorbed so that there is no objectionable sheen or glare-producing film of water on the core at the instant of film exposure.

A labeled lid, letter board, or another frame which allows one to portray the feature, drill hole number, photograph or core box number, and depths of the top and bottom of the cored interval should be included in the photograph. A scale of feet and/or tenths of feet or meters is optional if standard core boxes are used, but is useful for others examining photographs. An Engineer's folding ruler is ideal for this purpose.

Photographing Multiple Boxes

As soon as possible after the core is removed from the barrel and boxed the core should be photographed. To facilitate the photography, construct a frame capable of support three or more boxes at a time for use at the drill yard or core storage yard. Photograph the core dry then spray it with water to bring back the natural moisture color. The same precautions about glare referred to previously should be followed.

A frame which allows one to illustrate the project, feature, hole number, box ____of ____boxes, and from ____to ____, as a minimum, should be used for the photograph. Other optional but recommended entries may include date photographed, and a scale.

Special Circumstances

Special photography such as close-ups or macro-zoomed lens of shear zones, or other special features, is encouraged. When these small scale photographs are taken, the inclusion of a common object or scale should be included to provide the viewer with relative or actual dimensions.

When cores are coated with drill mud, a brush, wet rag, or pocket knife should be used to wash or scrape off the mud so that materials are their natural color and features of the core are not obscured. This step obviously must be taken prior to logging the material.

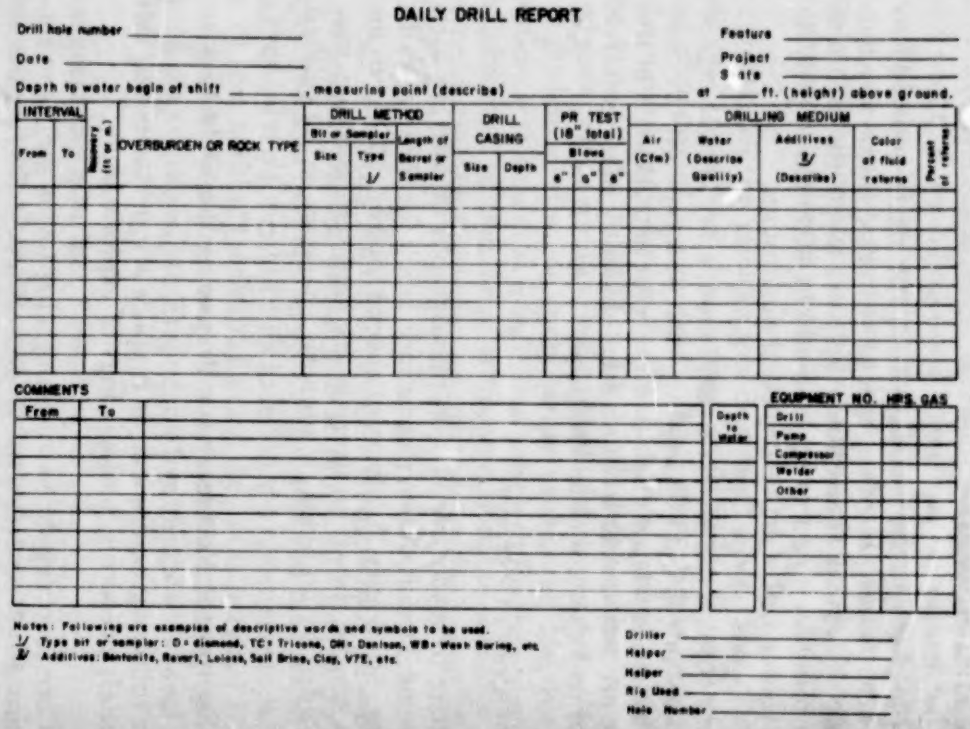
Photograph Overlays

Acetate or mylar overlays on photographs of core are used by some. Details shown may include labels for shears, weathering, lithologies, or items of special interest. Other items that may be shown on overlays are joint sets, and they may be coded by an alpha or numeric character or by colored ink.

Equipment Necessary for Preparing the Field Log

The following equipment or supplies are necessary for adequately preparing geologic logs of exploration:

> Core recovery sheets and rough log forms similar to figure 10–7 or NGEOSUB data sheets.—For recording core recovery and maintaining accurate depth measurements for determining core loss intervals.
>
> Drillers' reports.—To check measurements for core recovery, identifying changes in condition or contacts in intervals of poor recovery, determining reasons for core loss, and evaluating openness of fractures.



DAILY DRILL REPORT

Drill hole number ____________
Date ____________
Feature ____________
Project ____________
State ____________
Depth to water begin of shift ______, measuring point (describe) ____________ at ____ ft. (height) above ground.

INTERVAL		Recovery (ft or %)	OVERBURDEN OR ROCK TYPE	DRILL METHOD			DRILL CASING		PR TEST (18" total)			DRILLING MEDIUM				
				Bit or Sampler		Length of Barrel or Sampler			Blows			Air (Cfm)	Water (Describe Quality)	Additives 2/ (Describe)	Color of fluid returns	Percent of returns
From	To			Size	Type 1/		Size	Depth	6"	6"	6"					

COMMENTS

From	To	

Depth to Water

EQUIPMENT	NO.	HRS.	GAS
Drill			
Pump			
Compressor			
Welder			
Other			

Notes: Following are examples of descriptive words and symbols to be used.
1/ Type bit or sampler: D = diamond, TC = Tricone, DN = Denison, WB = Wash Boring, etc.
2/ Additives: Bentonite, Revert, Loiose, Salt Brine, Clay, VTE, etc.

Driller ____________
Helper ____________
Helper ____________
Rig Used ____________
Hole Number ____________

Figure 10-7. Daily drill report.

Knife.—Core hardness/strength characteristics; cleaning or scraping drill mud from core to allow logging and measurement of core recovery.

Hammer.—Core hardness/strength characteristics.

Tape measure or folding ruler.-(engineering scale with hundredths of feet or metric as appropriate).—Recovery measurements, thickness of units, shears and fillings, and spacing of fractures.

Protractor—Measuring orientation of contacts, bedding and foliation, and fracture orientation.

Hydrochloric acid.—Mineral or cementing agent identification (3:1 distilled water to acid).

Pocket magnifying glass.—Mineral or rock identification, minimum 10×.

Marking pen.—Waterproof ink for marking core for mechanical breaks, depth marks on core, sample marking.

Paintbrush and/or scrub brush, and water.—For cleaning core and for identifying wet color and incipient fractures.

Color identification charts (Munsel Color System or AGI color charts).

Filler block (spacer) material.—For identifying nonrecovery intervals, location of samples, and for recording drill depths.

Sample preparation materials.—Wax, heater, container.

Rock testing equipment.—Schmidt hammer, point load apparatus, pocket penetrometer or torvane.

Instruction to Drillers, Daily Drill Reports, and General Drilling Procedures

Driller/Geologist Relationship

The importance of communication between the geologist and driller cannot be overemphasized. Establishment of lines of communication, both orally and in writing, is a key to successful accomplishment of an exploration program.

Teamwork is essential! Geologists must recognize that their role in the drilling program is as an equal partner with the driller at the drill site. Establishment of this partnership at the beginning of the drilling program will result in better data. Failure to establish a good working relationship with the drill crew will inevitably result in unanswered questions and a poor quality end product. One way to establish good working rapport is to keep the drillers informed and to plan with them. Several types of instructions and drillers' prospectus reports follow.

Driller's Prospectus

A suggested method to assist in driller/geologist relationships is the preparation of a prospectus. The prospectus is prepared prior to starting the hole and after the geologist has used interpretive data to project what will be recovered and has determined whether special testing and procedures of deviations in standard practice will be required. This document provides the driller with information about safety, special site conditions, purpose of the hole, procedures to be followed, water testing requirements, materials expected to be recovered, any special sampling or geophysical testing required, and hole completion requirements.

Guidelines for Drillers

Most of the following paragraphs contain general instructions for drillers. These instructions may not be as detailed or precise as those used in many field offices. However, they provide a framework upon which individual geologists or field offices may prepare written guidelines for drill crews or for contract drillers. Also, they may serve to help geologists correct poor drilling procedures, collect additional data, or improve core handling and logging.

Drilling Setup Instructions.—To ensure that drill holes are completed at the desired location, and along the correct bearing and plunge, the use of aiming stakes and a suitable device for measuring angles should be established by the geologist and used by the drill crews. Drillers should use aiming stakes set by geologist for the specified bearing of the drill hole. The rig must be anchored properly so that it will not shift. If stakes have been removed or knocked over, they should be replaced by the geologist. Also, drillers must ensure the hole is drilled at the designated angle. The geologist should check the plunge angle with Brunton compass, and/or the drillers should use an appropriate measuring device.

Daily Drill Reports Preparation.—The drillers should prepare duplicate daily drill reports using carbon paper (three copies of each report may be required on contract rigs). All copies must be legible and preferably printed. One copy should be provided to the geologist for monitoring progress and for preparation of the geologic log. The drill report has a space opposite each run for each item of information required; if any of these spaces are left blank, the report is incorrectly filled out. Data should be added to the report or recorded in a notebook after each run. Drillers should record data as it occurs. See drawing 40–D–6484 (fig. 10–7) as an example for reporting daily drill activities. Many field offices have local forms on which these data can be recorded. Comments regarding specific items to be recorded and reported on the daily reports are contained in the following paragraphs.

1. Recording Depths and Core Loss.—Check for agreement on depths for intervals drilled by consecutive shifts. Depths should be recorded in feet and tenths of feet or to the nearest one-hundredth of a meter, as appropriate. Tape checks or rod checks may be required at change of shift or more frequently when requested by the geologist. The section entitled "Core Recovery and Core Losses" contains instructions for proper use of core measurements, filler blocks (spacers), and tape checks. The driller is responsible for knowing the depth of the barrel and the hole at all times. Any discrepancies between intervals drilled and recovery must be avoided. Only standard length drill rods should be used. Core recovery should be measured both while core is still in the inner barrel and after it is placed in the core box. Record the most correct measurement of the two in the report. In the event core is left in the hole, core loss is noted,

and the next run will be shortened accordingly; the lost amount and proper hole entry and startup procedures will be followed to facilitate recovery.

2. Recording Drilling Conditions.—Make sure drilling conditions, such as fast or slow, hard or soft, rough or smooth, even or erratic, moderately fast or very slow, bit blocks off are indicated for each run. Record time in minutes per foot of penetration. Any changes in the drilling rate within a run also should be noted along with intervals of caving or raveling. If the bit becomes plugged or blocking off is suspected, the driller should stop drilling and pull the core barrel. Also, when drill circulation is lost, the driller should pull and examine the core.

3. Drilling Fluid Return and Color.—The type, color, and estimated percent of drilling fluids returned shall be recorded for each core run drilled. The depth of changes in fluid loss or color is particularly important. If drilling mud is used, indicate number of sacks used per shift. In case of total loss of drilling fluid, it may be necessary to pull and perform pressure testing.

4. Description of Core.—Drillers need to describe the core in general terms; i.e., moderately hard, very hard, soft, clay seams, broken color, etc. If familiar with the rock types, drillers may report more than just general terminology.

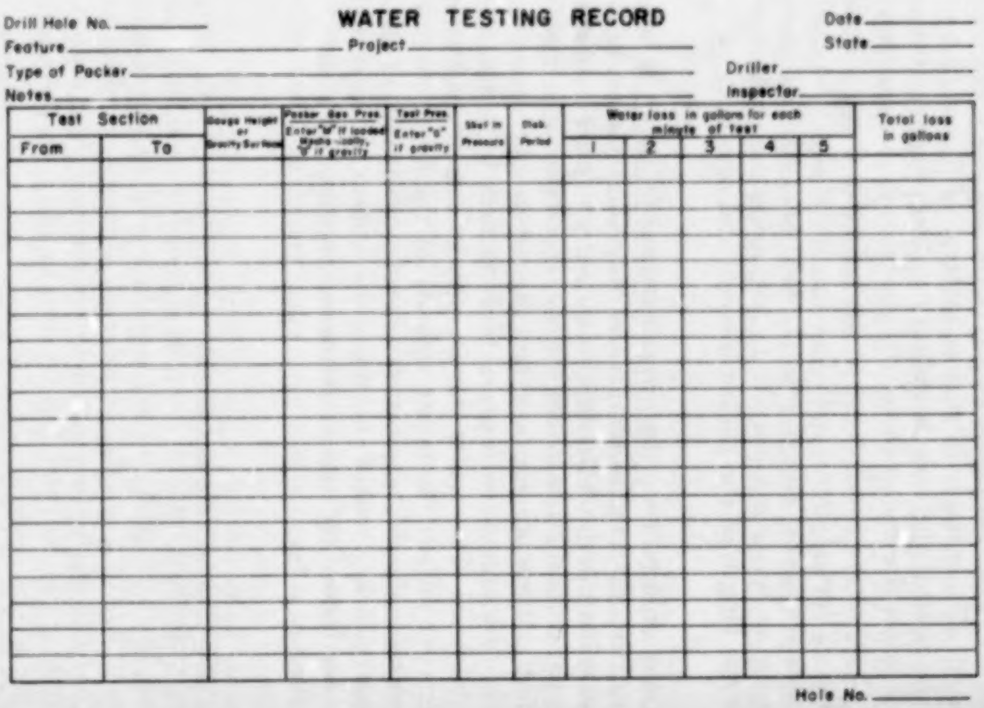
5. Water-Pressure Testing.—Unless instructed otherwise, all holes in rock are to be water tested at depths below 25 feet (7.6 m) at 10-foot (3 m) intervals, at pressures of approximately 1 lb/in^2 (619 kPa) per foot of cover up to 100 lb/in^2 (690 kPa). NOTE: Standard pressures of 25, 50, and 100 lb/in^2 (172.5-, 345- and 690-kPa) normally will be used. The instructions for "standard" pressures must be modified for each site; drill assignments by the design team will provide detailed instructions for water testing. Factors such as density of materials, "overburden pressure" or "cover," purpose of testing, distances from free faces (horizontal overburden pressure), water levels, and artesian pressures all must be taken into account so that pressure testing does not hydro-fracture the foundation materials or push off a cliff face. Higher pressures should not be used unless

instructed to do so by the geologist. If a range of pressures is used and disproportionately high water losses are obtained at the higher pressures, water losses at the lower pressures should be recorded as the pressures are stepped down. To ensure complete test data, gravity tests, overlapping pressure tests, and variations in the length of the interval tested may be used. For example, a packer interval of 8 feet (2.4 m) may be used if the hole is caving too badly to get 10 feet (3 m) below the casing. Also, if a packer will not seat at 10 feet (3 m) above the bottom of the hole and there is good rock at 12 feet (3.66 m), a 12-foot test interval maybe used. If losses are above 15 gal/min (1.146L/sec), exceed pump capacity, or water is known to be bypassing the packer, reduce the length of the packer interval and retest.

Losses should be recorded in gallons and tenths of gallons per minute, (liters per second) and only water meters reading in gallons per minute should be used (calculate to obtain liters per second). The driller should record the water meter reading at 1-minute intervals, and the test should be run for a full 5 minutes at each pressure increment after the loss has stabilized. The driller should report the average loss in gallons per minute (liters per second) for the 5-minute test. Each driller should keep his own record of the packer data in case questions arise concerning the testing. A suggested form for recording data is shown on drawing 40–D–6482, fig. 10–8.

6. Casing or Cementing Depths.—The depth of the casing or the cemented interval must be shown for each core run drilled. Do not cement any more of the hole than is necessary to repair a caving or raveling interval. (The use of additives such as calcium chloride or aluminum powder, if permitted, will reduce the set time; but be sure to add it to the water and not to the cement).

7. Recording Unusual Conditions.—All unusual conditions or events should be noted in the "Notes" column of the report. This includes such items as sudden changes in drilling speed, loss of circulations, drop of drill string (open joints or cavities), casing and cementing procedures, caving, squeezing, packer failures, gas.



WATER TESTING RECORD

Drill Hole No. ________
Feature ________ Project ________
Type of Packer ________
Notes ________
Date ________
State ________
Driller ________
Inspector ________

Test Section		Gauge Height or Gravity Surface	Packer Gas Pres. Enter "M" if loaded Mechanically, "G" if gravity	Test Pres. Enter "G" if gravity	Shut in Pressure	Stab. Period	Water loss in gallons for each minute of test					Total loss in gallons
From	To						1	2	3	4	5	

Hole No. ________

Figure 10-8. Water testing record.

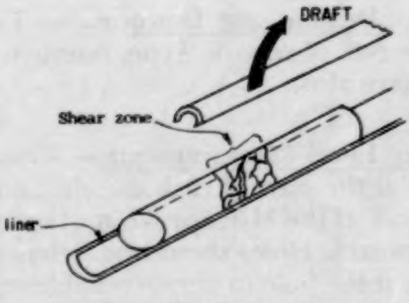
8. Recording Setup, Drilling, and Downtime.—Time must be noted on reverse side of report. Type, number, and size of bit is indicated here also.

9. Recording Water Level Measurements.—Measurement should be recorded at the start of each day shift and shown on the day shift report. If the M-scope is out of order, notify the geologist or foreman. Holes should be jetted or bailed prior to completion of the hole to obtain reliable water level data. Immediately after jetting or bailing, the depth to water should be recorded.

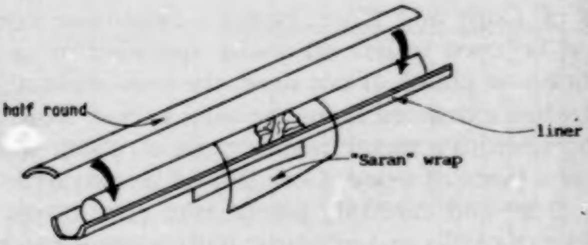
Care of Core and Core Boxes.—Split-tube core barrels should be used unless otherwise specified or required by condition or policy. If not used, the core must not be damaged when extracted from the solid barrel. Do not beat on the barrel with a metal hammer; use a rubber mallet/hammer or a piece of wood. Core should be extracted from the inner tube and carefully placed into core boxes by hand. The use of cardboard or plastic halfrounds is recommended (see fig. 10–9). Core pieces must be fitted into the core box and fragments should be arranged to save space. Long pieces may be broken for better fit in the core box, but a checkmark should be made on the core to denote inflicted (mechanical) breaks. Currently there are two or more different size core boxes being used. If 5-foot (1.5 m) core boxes are used, it eliminates the need for mechanical breaks to fit 5-foot runs in boxes. Figure 10–10 shows Reclamation's standard core box for N-size core.

Core should be placed in the core box from left to right, with the top to the left, bottom to the right. When the core is placed in the box as described above, the left end of the box should be marked with black enamel paint and the right side left blank. Core blocks which record the depths will be placed in the tray on the right side of the box. Data on the outside of the left end of the box should include the project, feature, drill hole number, box number, and depth interval in the box.

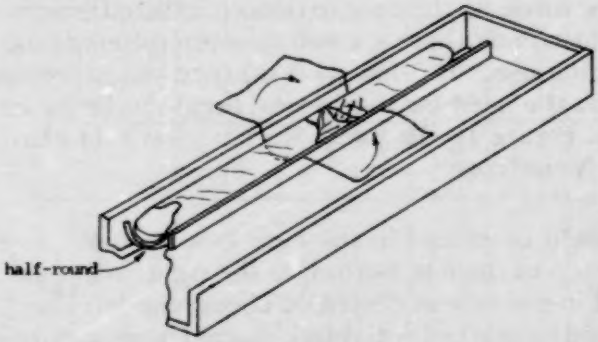
Filler blocks (spacers) are necessary to properly record information and minimize disturbance to the core during handling. Blocks should be placed with the finished side (painted



1. Remove upper split liner to expose fractured rock o
shear zone.



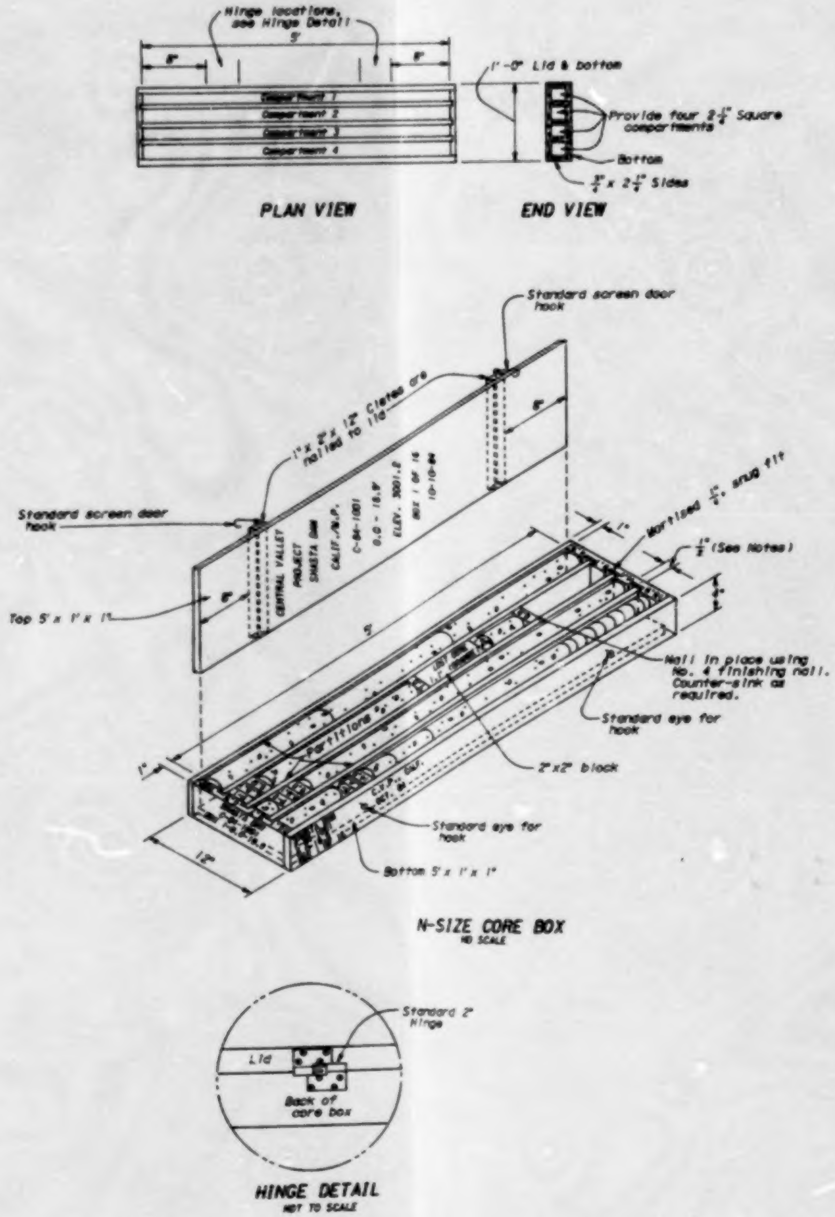
2. Place "Saran" wrap over shear zone; then place half
round over top of core and wrap.



3. Take to core box, rotate liner, half-round and core 180°
and place in core box; then wrap "Saran" wrap over top o
core. An additional half-round may then be placed over th
zone to protect it, or to write on. Shear zone may be lifte
out of box as a unit if waxing of sample is desired.

Figure 10-9.—Use of a cardboard PVC half-round and plastic wrap to prevent disturbance and drying out of shear zone, special samples, or fracture zones.

[illegible]



NOTES

1. Box construction - Ends, sides, partitions, lid, and bottom shall be 1-inch nominal thickness from commercial grade No. 2 pine or better, and surfaced on all sides. The grain shall be parallel to the long axis. All pieces shall be seasoned to prevent objectional warping. All joints shall be securely fastened with 8d ring-shank nails, spaced on not over 6-inch centers and with at least two nails at each corner. The end shall be mortised 1/4 inch deep to accept partitions. The lid and bottom shall fit snugly within the frame work of the box.

2. Partitions shall be nominally 5 feet-long, 2-1/4 inches high, and 1/2 inch - thick. (See Note 12).

3. Spacer blocks. - Twelve spacer blocks shall be required for each box. Spacer blocks shall be constructed of 1-inch nominal clear lumber, 2-1/4 inches square, and are to be nailed in place at the bottom of each core run with number 4 finishing nails. Spacer blocks shall be painted white. These blocks shall be labeled to show: Run or Run pull number, depth of that Run, and the amount of lost core (or gain) that occurred during that run. Should some core be left in the hole, the driller shall limit his run so as not to overfill the core barrel. The gain shall be recorded when recovered.

4. Core loss blocks. - Core loss blocks shall be constructed from standard 2-by 2-inch wood or styrofoam stock. The length of these blocks shall be equivalent to the core loss interval and shall be inserted in the run wherever core loss occurs, with the exception that for accumulated (interval indeterminable) core loss, the block shall be placed at the end of the run and before the spacer block. Core loss blocks shall be painted fluorescent orange or tangerine.

5. Workmanship. - Boxes shall be constructed substantially to withstand rough usage and shall be nailed to secure members without splitting.

6. Core box labeling. - Labeling shall be stencilled on each box with black waterproof paint or equivalent. The following items shall be marked on the interior and exterior center of the lid:
   - A. Feature
   - B. Project
   - C. Region/State
   - D. Drill hole number
   - E. Surface Elevation/Location w/stationing
   - F. Drill interval
   - G. Box of boxes
   - H. Date

7. Feature Hole Number, depths and box number shall be stencilled on both ends of each box.

8. Depths in feet and tenths of a foot (meters) shall be marked clearly with a black-waterproof felt-tip pen, or equivalent, on the top of both box ends for each core compartment and the top of each spacer block. Core loss blocks shall be marked in like manner with the top and bottom of the loss interval. Core depths shall be marked at the top and bottom of each pattern.

9. Handling of core and boxes. - The top of the core shall be placed at the back left corner of the box, and the remaining core shall be placed proceeding left to right, back to front, throughout the remaining core compartments.

10. Unused portions of the partitions shall be filled with 2 by 2-inch wood or styrofoam stock, cut to fit.

11. Nail the lid into place only if required.

12. Clear plastic half rounds cut from PVC pipe are to be used when core is particularily susceptible to disturbance during handling and storage. If orientation of geologic features is anticipated when core is broken in short segments the core should be enclosed in two clear plastic half rounds and secured by tape. The inside diameter of the PVC pipe must be equivalent to the outside diameter of the core. For core handling and use of half rounds See figure II 10-17.
To accomodate the use of half rounds, modification may be required to the compartmental dimensions shown for the construction of the core box.

ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

ENGINEERING GEOLOGY MANUAL

N-SIZE CORE BOX

DESIGNED [illegible] TECHNICAL APPROVAL M.L. Hill
DRAWN [illegible] SUBMITTED M.L. Hill
CHECKED [illegible] APPROVED [illegible]
DENVER, COLORADO [illegible] 102-D-9

Figure 10-10. N-Size core box.

hite) up and marked with either black enamel paint or lowmaster-type pen (2- by 2-inch [50 × 50 mm] blocks work ell for N-size core). All core runs must be separated with locks properly labeled with pull number and/or core epth. Sample intervals should be marked in the boxes using ooden blocks of lengths equal to the missing core so that e sample may be placed back in the box. Gaps for core sses shall not be left in the core box. Core left in the hole nd recovered on the next run may be added to the previous un. Filler blocks inserted where unaccountable core losses ccur will be marked to show the length of loss in tenths of et, as follows: LC (lost core) 0.3 foot, or NR (no recovery) .3 foot. The core loss block indicates that a certain length f core was unaccountably lost within a run and it should e placed at the depth of the core loss. If the point of core ss occurrence cannot be determined, the block shall be laced in the core box at the bottom of the run, preceding e bottom of run block. In the case of cavities, the cavity ay be marked on the block. All spacer, samples, and core ss blocks shall be nailed to the bottom or sides of the box prevent movement of the core.

t the drill site, core boxes should be lined up, preferably n boards or planks, in order from top to bottom, with labels nd up side to left, in a safe area and kept covered with lids. hile in the field, do not place boxes where sliding or caving f slopes is likely to occur and keep out of the way of vehicles nd equipment. Core boxes, especially those containing soft, aking, or intensely fractured core material must be covered nmediately to prevent damage by rain or drying. Tray par- tions in boxes should be nailed so that nails do not protrude rom bottom of boxes.

o not remove core boxes from the drill hole location unless equested to do so by the geologist. When the core is moved, should be done so carefully to prevent disturbance, break- ge, or spilling of core. Protection of the core during trans- ortation can be maximized by the use of nailed-down acers and a reusable 3/4- to 1-inch thick (19 - 25 mm) am-rubber pad placed between the top of the core and e secured core box lid.

ole Completion.—Completion of the drill hole shall con- rm to the requirements established by the exploration program requirements and the direction of the field geologist. General instructions and procedures for hole completion are:

> Drill holes usually will be completed either with sufficient casing or plastic pipe to assure that they stay open for later water level observations. In areas where vandalism may occur or when long-term monitoring is contemplated, a suitable cap with a locking device, should be installed. Completion information should be indicated on the driller's report.
>
> A hole to be left open is not completed until it is properly marked. A 2- by 4-inch (50 × 100 mm) or 4- by 4-inch (100 × 100 mm) board painted white and with the number of the hole printed in black enamel paint may be suitable. If ground-water observation riser pipes have been installed, it is often beneficial to install a minimum 3–foot (1 m) length of surface casing, with a locking cap, as a standpipe to mark the drill hole and protect the piezometer. Grounded in place, this standpipe can also serve to protect the observation well from infiltration by surface runoff.

Chapter 11

INSTRUCTIONS FOR LOGGING SOILS AND SURFICIAL DEPOSITS

General

All Bureau of Reclamation subsurface investigations of soils for construction materials and for most engineering purposes using test pits, trenches, auger holes, drill holes, or other exploratory methods shall be logged and described using the standards in USBR 5000 [1] and 5005 [2] (modified Unified Soil Classification System) in accordance with the established descriptive criteria and descriptors presented in Chapter 3 and the guidelines presented in this section.

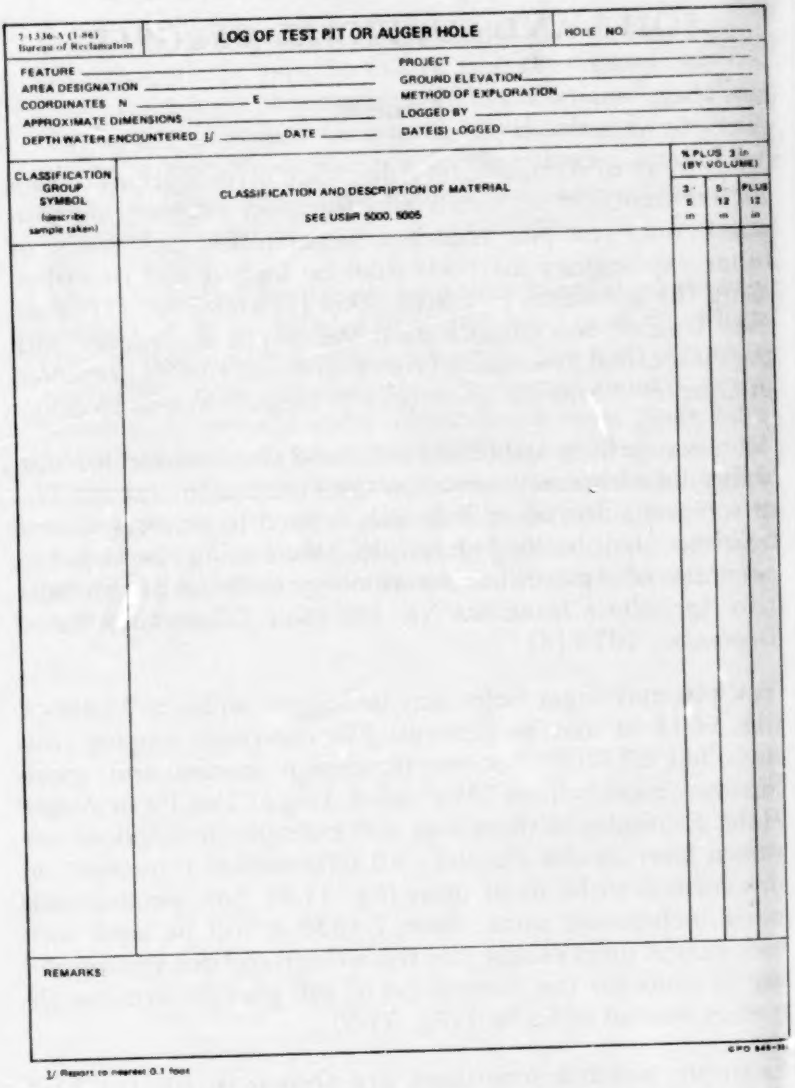
All investigations associated with land classification for suitability for irrigation, as well as data collection and analyses of soil and substratum materials related to drainage investigations, shall be logged and described using the U.S. Department of Agriculture terminology outlined in appendix I to *Agriculture Handbook No. 436* (Soil Taxonomy), dated December 1975 [3].

Test pits and auger holes may be logged on form 7-1336-A (fig. 11-1), or may be generated by computer logging routines (AUGLOG). For metric design studies and specifications, modify form 7M-1336-A, Log of Test Pit or Auger Hole. Examples of these logs and example descriptions are shown later in this chapter. All information requested on this form is to be in SI units (fig. 11-2). For specifications using inch-pound units, form 7-1336-A will be used with inch-pound units except that the written soil description will use SI units for the description of soil particle sizes, (millimeters instead of inches) (fig. 11-2).

Example word descriptions are shown in figures 11-2 through 11-11. Some examples are presented in the SI format while others are in the inch-pound unit format.

For reporting maximum particle size, use the following:

Fine sand
Medium sand



7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. ____

FEATURE ____
AREA DESIGNATION ____
COORDINATES N ____ E ____
APPROXIMATE DIMENSIONS ____
DEPTH WATER ENCOUNTERED 1/ ____ DATE ____

PROJECT ____
GROUND ELEVATION ____
METHOD OF EXPLORATION ____
LOGGED BY ____
DATE(S) LOGGED ____

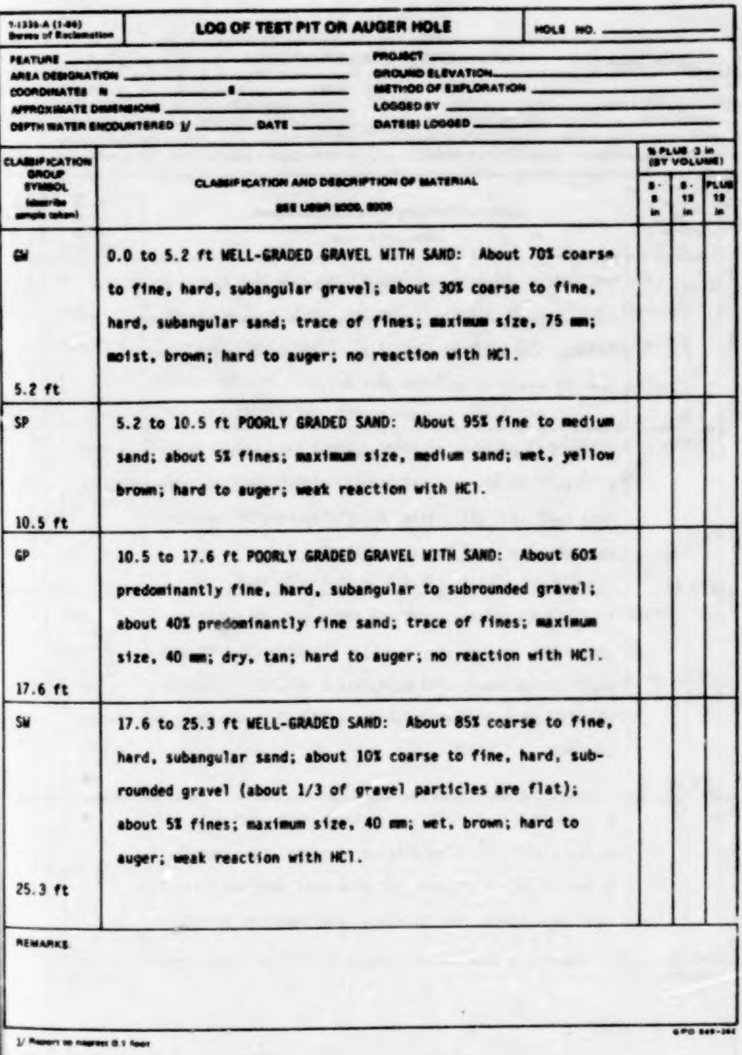
CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME)		
		3-5 in	5-12 in	PLUS 12 in

REMARKS:

GPO 845-31

1/ Report to nearest 0.1 foot

Figure 11-1. Log of test pit or auger hole.



7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. ____________

FEATURE ____________
AREA DESIGNATION ____________
COORDINATES N ________ E ________
APPROXIMATE DIMENSIONS ____________
DEPTH WATER ENCOUNTERED 1/ ________ DATE ________

PROJECT ____________
GROUND ELEVATION ____________
METHOD OF EXPLORATION ____________
LOGGED BY ____________
DATE(S) LOGGED ____________

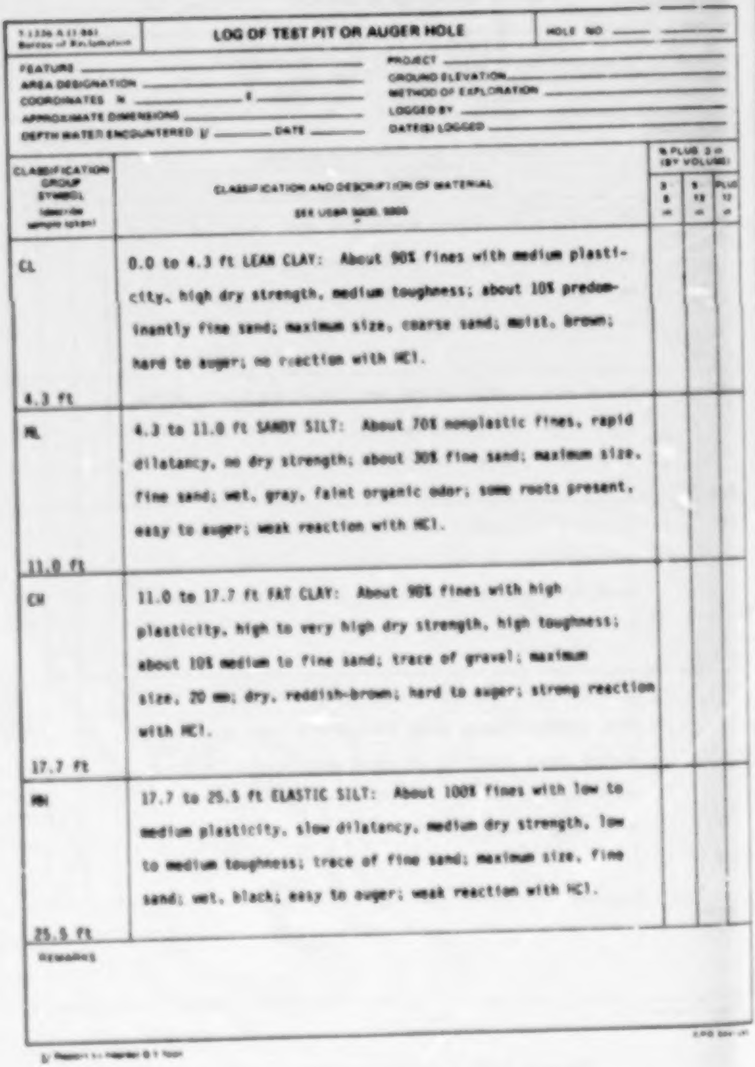
CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME)		
		3-5 in	5-12 in	PLUS 12 in
GW 5.2 ft	0.0 to 5.2 ft WELL-GRADED GRAVEL WITH SAND: About 70% coarse to fine, hard, subangular gravel; about 30% coarse to fine, hard, subangular sand; trace of fines; maximum size, 75 mm; moist, brown; hard to auger; no reaction with HCl.			
SP 10.5 ft	5.2 to 10.5 ft POORLY GRADED SAND: About 95% fine to medium sand; about 5% fines; maximum size, medium sand; wet, yellow brown; hard to auger; weak reaction with HCl.			
GP 17.6 ft	10.5 to 17.6 ft POORLY GRADED GRAVEL WITH SAND: About 60% predominantly fine, hard, subangular to subrounded gravel; about 40% predominantly fine sand; trace of fines; maximum size, 40 mm; dry, tan; hard to auger; no reaction with HCl.			
SW 25.3 ft	17.6 to 25.3 ft WELL-GRADED SAND: About 85% coarse to fine, hard, subangular sand; about 10% coarse to fine, hard, subrounded gravel (about 1/3 of gravel particles are flat); about 5% fines; maximum size, 40 mm; wet, brown; hard to auger; weak reaction with HCl.			

REMARKS:

1/ Report to nearest 0.1 foot

GPO 849-284

Figure 11-2. Clean coarse-grained soils.



7-1336 A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. ______

FEATURE ______
AREA DESIGNATION ______
COORDINATES N ______ E ______
APPROXIMATE DIMENSIONS ______
DEPTH WATER ENCOUNTERED 1/ ______ DATE ______

PROJECT ______
GROUND ELEVATION ______
METHOD OF EXPLORATION ______
LOGGED BY ______
DATE(S) LOGGED ______

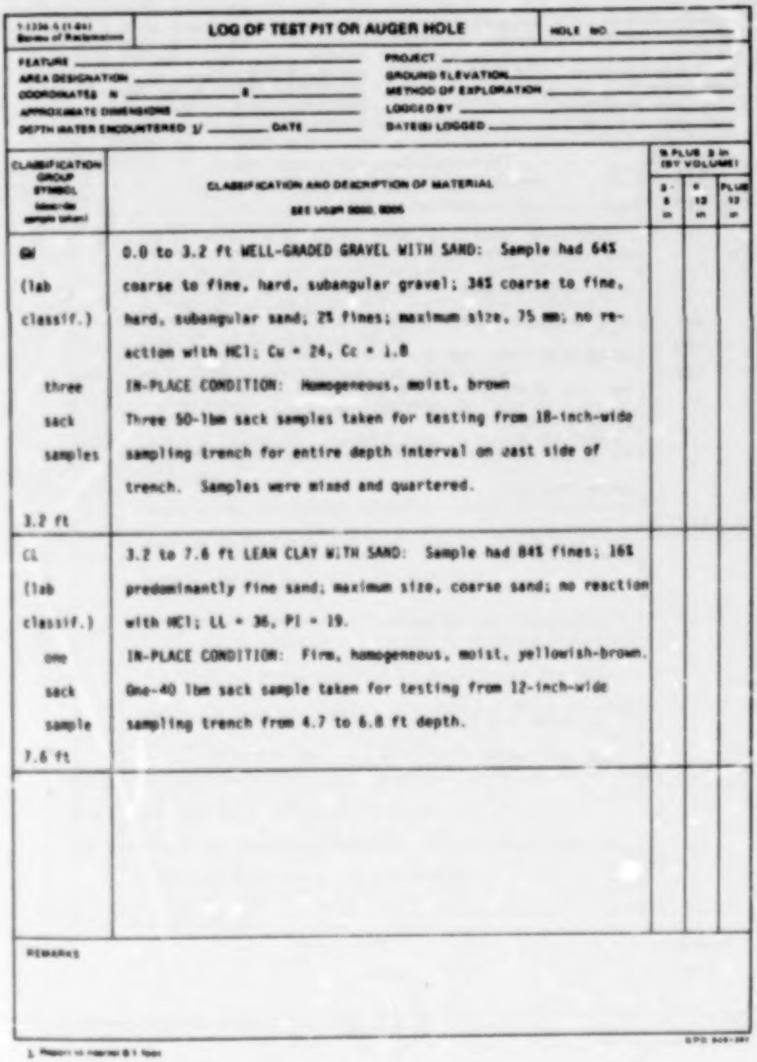
CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME)		
		3-5 in	5-12 in	PLUS 12 in
CL 4.3 ft	0.0 to 4.3 ft LEAN CLAY: About 90% fines with medium plasticity, high dry strength, medium toughness; about 10% predominantly fine sand; maximum size, coarse sand; moist, brown; hard to auger; no reaction with HCl.			
ML 11.0 ft	4.3 to 11.0 ft SANDY SILT: About 70% nonplastic fines, rapid dilatancy, no dry strength; about 30% fine sand; maximum size, fine sand; wet, gray, faint organic odor; some roots present, easy to auger; weak reaction with HCl.			
CH 17.7 ft	11.0 to 17.7 ft FAT CLAY: About 90% fines with high plasticity, high to very high dry strength, high toughness; about 10% medium to fine sand; trace of gravel; maximum size, 20 mm; dry, reddish-brown; hard to auger; strong reaction with HCl.			
MH 25.5 ft	17.7 to 25.5 ft ELASTIC SILT: About 100% fines with low to medium plasticity, slow dilatancy, medium dry strength, low to medium toughness; trace of fine sand; maximum size, fine sand; wet, black; easy to auger; weak reaction with HCl.			

REMARKS

[illegible]

1/ Report to nearest 0.1 foot

Figure 11-3. Fine-grained soils.



Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

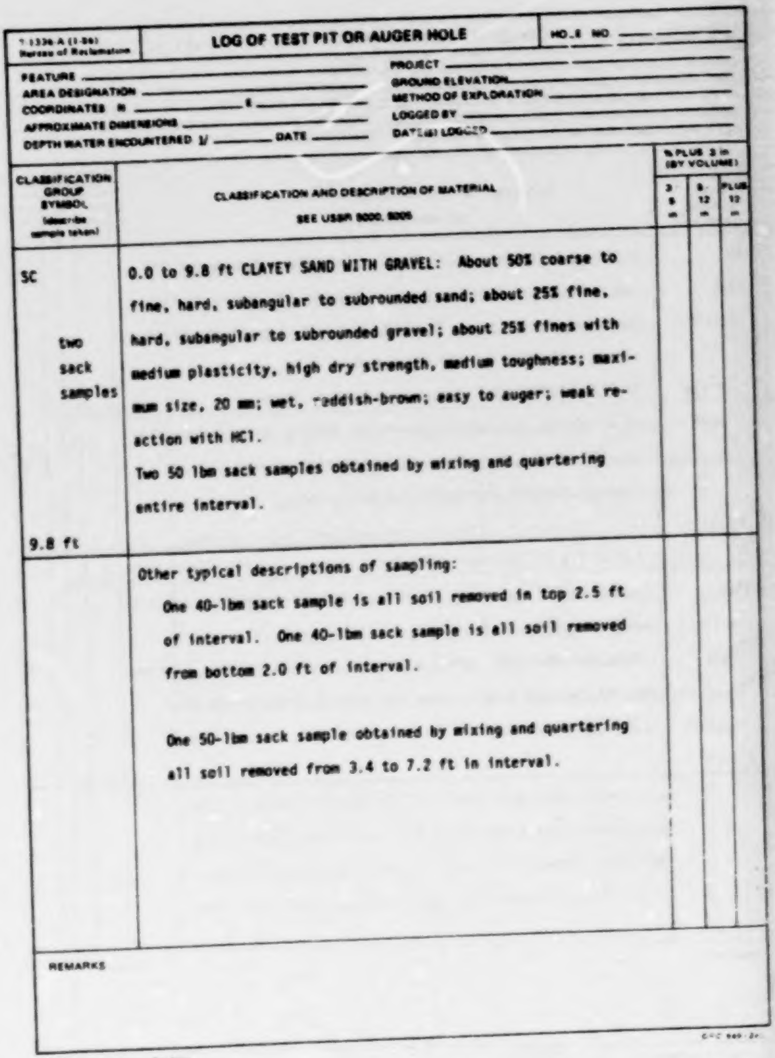
HOLE NO. ______

FEATURE ______
AREA DESIGNATION ______
COORDINATES N ______ E ______
APPROXIMATE DIMENSIONS ______
DEPTH WATER ENCOUNTERED 1/ ______ DATE ______
PROJECT ______
GROUND ELEVATION ______
METHOD OF EXPLORATION ______
LOGGED BY ______
DATE(S) LOGGED ______

CLASSIFICATION GROUP SYMBOL	CLASSIFICATION AND DESCRIPTION OF MATERIAL	% PLUS 3 in (BY VOLUME)		
		3-5 in	5-12 in	PLUS 12 in
GW (lab classif.) three sack samples 3.2 ft	0.0 to 3.2 ft WELL-GRADED GRAVEL WITH SAND: Sample had 64% coarse to fine, hard, subangular gravel; 34% coarse to fine, hard, subangular sand; 2% fines; maximum size, 75 mm; no reaction with HCl; Cu = 24, Cc = 1.8 IN-PLACE CONDITION: Homogeneous, moist, brown Three 50-lbm sack samples taken for testing from 18-inch-wide sampling trench for entire depth interval on east side of trench. Samples were mixed and quartered.			
CL (lab classif.) one sack sample 7.6 ft	3.2 to 7.6 ft LEAN CLAY WITH SAND: Sample had 84% fines; 16% predominantly fine sand; maximum size, coarse sand; no reaction with HCl; LL = 36, PI = 19. IN-PLACE CONDITION: Firm, homogeneous, moist, yellowish-brown. One-40 lbm sack sample taken for testing from 12-inch-wide sampling trench from 4.7 to 6.8 ft depth.			

REMARKS

Figure 11-4. Soil classifications based on laboratory test data.



7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. ______

FEATURE ______
AREA DESIGNATION ______
COORDINATES N ______ E ______
APPROXIMATE DIMENSIONS ______
DEPTH WATER ENCOUNTERED 1/ ______ DATE ______

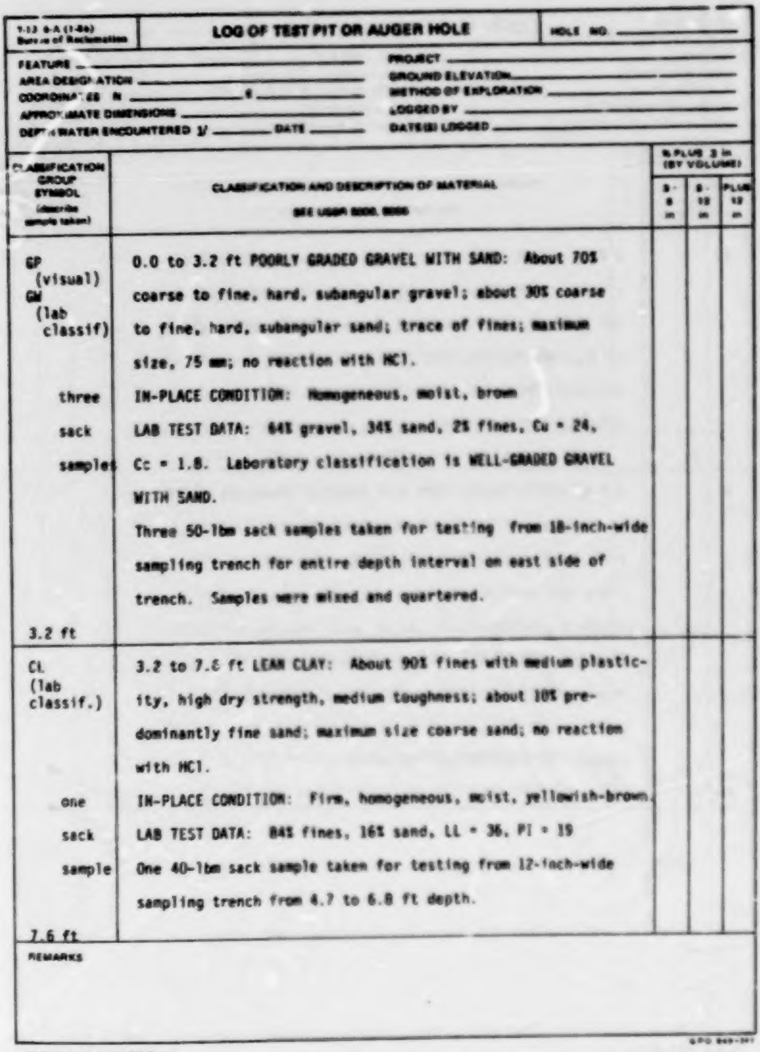
PROJECT ______
GROUND ELEVATION ______
METHOD OF EXPLORATION ______
LOGGED BY ______
DATE(S) LOGGED ______

CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME) 3-5 in	5-12 in	PLUS 12 in
SC two sack samples 9.8 ft	0.0 to 9.8 ft CLAYEY SAND WITH GRAVEL: About 50% coarse to fine, hard, subangular to subrounded sand; about 25% fine, hard, subangular to subrounded gravel; about 25% fines with medium plasticity, high dry strength, medium toughness; maximum size, 20 mm; wet, reddish-brown; easy to auger; weak reaction with HCl. Two 50 lbm sack samples obtained by mixing and quartering entire interval.			
	Other typical descriptions of sampling: One 40-lbm sack sample is all soil removed in top 2.5 ft of interval. One 40-lbm sack sample is all soil removed from bottom 2.0 ft of interval. One 50-lbm sack sample obtained by mixing and quartering all soil removed from 3.4 to 7.2 ft in interval.			

REMARKS

1/ Report to nearest 0.1 foot

Figure 11-5. Auger hole with samples taken.



7-13 6-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. ______

FEATURE ______
AREA DESIGNATION ______
COORDINATES N ______ E ______
APPROXIMATE DIMENSIONS ______
DEPTH WATER ENCOUNTERED 1/ ______ DATE ______
PROJECT ______
GROUND ELEVATION ______
METHOD OF EXPLORATION ______
LOGGED BY ______
DATE(S) LOGGED ______

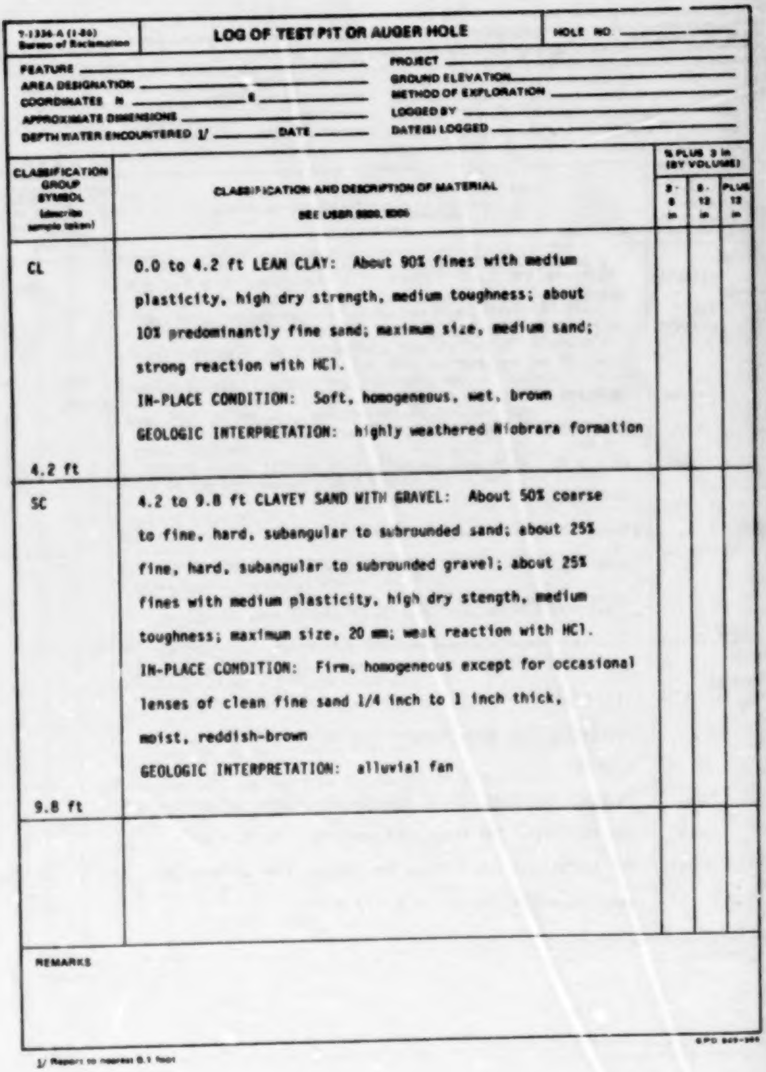
CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME)		
		3-6 in	6-12 in	PLUS 12 in
GP (visual) GM (lab classif) three sack samples 3.2 ft	0.0 to 3.2 ft POORLY GRADED GRAVEL WITH SAND: About 70% coarse to fine, hard, subangular gravel; about 30% coarse to fine, hard, subangular sand; trace of fines; maximum size, 75 mm; no reaction with HCl. IN-PLACE CONDITION: Homogeneous, moist, brown LAB TEST DATA: 64% gravel, 34% sand, 2% fines, Cu = 24, Cc = 1.8. Laboratory classification is WELL-GRADED GRAVEL WITH SAND. Three 50-lbm sack samples taken for testing from 18-inch-wide sampling trench for entire depth interval on east side of trench. Samples were mixed and quartered.			
CL (lab classif.) one sack sample 7.6 ft	3.2 to 7.6 ft LEAN CLAY: About 90% fines with medium plasticity, high dry strength, medium toughness; about 10% predominantly fine sand; maximum size coarse sand; no reaction with HCl. IN-PLACE CONDITION: Firm, homogeneous, moist, yellowish-brown. LAB TEST DATA: 84% fines, 16% sand, LL = 36, PI = 19 One 40-lbm sack sample taken for testing from 12-inch-wide sampling trench from 4.7 to 6.8 ft depth.			

REMARKS

1/ Report to nearest 0.1 foot

GPO 849-[illegible]

Figure 11-6. Reporting laboratory classification in addition to visual classification.



7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. ____________

FEATURE ____________
AREA DESIGNATION ____________
COORDINATES N ____________ E ____________
APPROXIMATE DIMENSIONS ____________
DEPTH WATER ENCOUNTERED 1/ ____________ DATE ____________

PROJECT ____________
GROUND ELEVATION ____________
METHOD OF EXPLORATION ____________
LOGGED BY ____________
DATE(S) LOGGED ____________

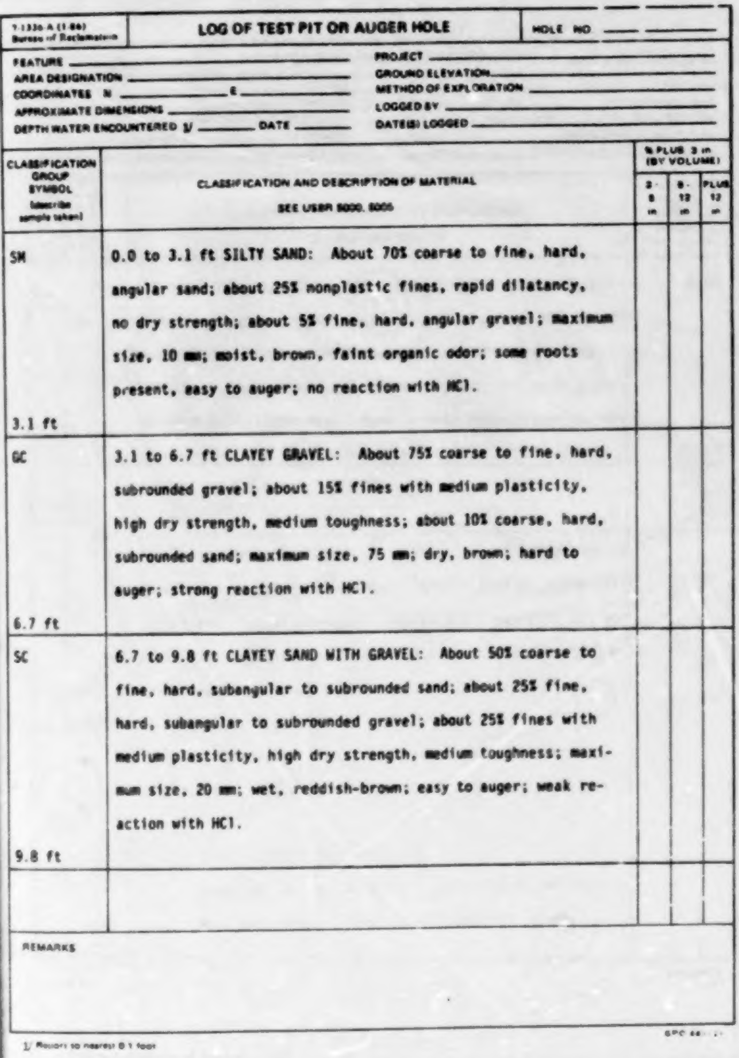
CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME)		
		3-6 in	6-12 in	PLUS 12 in
CL 4.2 ft	0.0 to 4.2 ft LEAN CLAY: About 90% fines with medium plasticity, high dry strength, medium toughness; about 10% predominantly fine sand; maximum size, medium sand; strong reaction with HCl. IN-PLACE CONDITION: Soft, homogeneous, wet, brown GEOLOGIC INTERPRETATION: highly weathered Niobrara formation			
SC 9.8 ft	4.2 to 9.8 ft CLAYEY SAND WITH GRAVEL: About 50% coarse to fine, hard, subangular to subrounded sand; about 25% fine, hard, subangular to subrounded gravel; about 25% fines with medium plasticity, high dry stength, medium toughness; maximum size, 20 mm; weak reaction with HCl. IN-PLACE CONDITION: Firm, homogeneous except for occasional lenses of clean fine sand 1/4 inch to 1 inch thick, moist, reddish-brown GEOLOGIC INTERPRETATION: alluvial fan			

REMARKS

GPO [illegible]

1/ Report to nearest 0.1 foot

Figure 11-7. Undisturbed soils.



7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. ______

FEATURE ______
AREA DESIGNATION ______
COORDINATES N ______ E ______
APPROXIMATE DIMENSIONS ______
DEPTH WATER ENCOUNTERED 1/ ______ DATE ______

PROJECT ______
GROUND ELEVATION ______
METHOD OF EXPLORATION ______
LOGGED BY ______
DATE(S) LOGGED ______

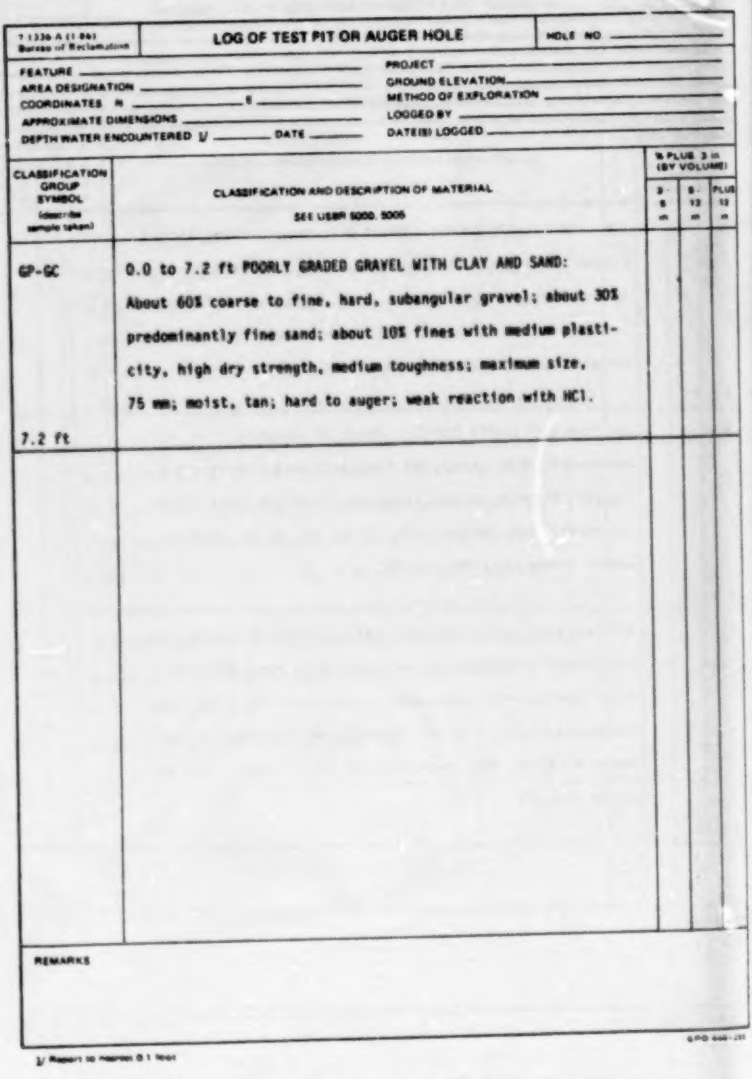
CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME)		
		3-8 in	8-12 in	PLUS 12 in
SM 3.1 ft	0.0 to 3.1 ft SILTY SAND: About 70% coarse to fine, hard, angular sand; about 25% nonplastic fines, rapid dilatancy, no dry strength; about 5% fine, hard, angular gravel; maximum size, 10 mm; moist, brown, faint organic odor; some roots present, easy to auger; no reaction with HCl.			
GC 6.7 ft	3.1 to 6.7 ft CLAYEY GRAVEL: About 75% coarse to fine, hard, subrounded gravel; about 15% fines with medium plasticity, high dry strength, medium toughness; about 10% coarse, hard, subrounded sand; maximum size, 75 mm; dry, brown; hard to auger; strong reaction with HCl.			
SC 9.8 ft	6.7 to 9.8 ft CLAYEY SAND WITH GRAVEL: About 50% coarse to fine, hard, subangular to subrounded sand; about 25% fine, hard, subangular to subrounded gravel; about 25% fines with medium plasticity, high dry strength, medium toughness; maximum size, 20 mm; wet, reddish-brown; easy to auger; weak reaction with HCl.			

REMARKS

1/ Report to nearest 0.1 foot

GPO [illegible]

Figure 11-8. Coarse-grained soils with fines.



7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. ____

FEATURE ____
AREA DESIGNATION ____
COORDINATES N ____ E ____
APPROXIMATE DIMENSIONS ____
DEPTH WATER ENCOUNTERED 1/ ____ DATE ____

PROJECT ____
GROUND ELEVATION ____
METHOD OF EXPLORATION ____
LOGGED BY ____
DATE(S) LOGGED ____

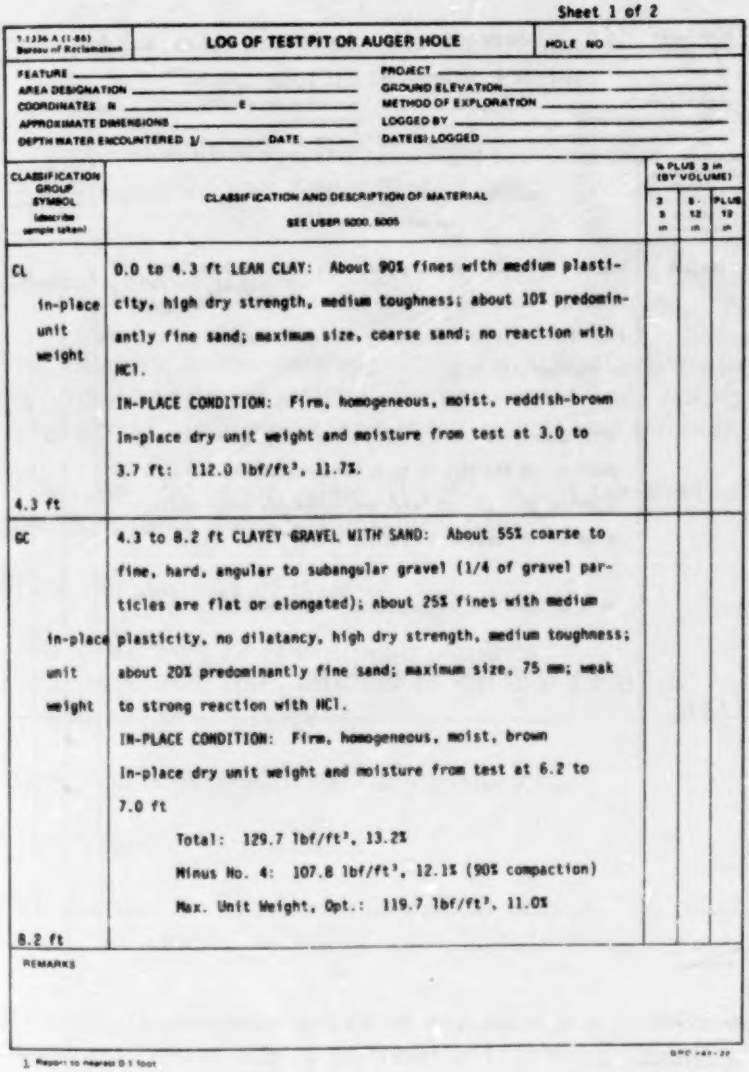
CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME) 3-5 in	5-12 in	PLUS 12 in
GP-GC 7.2 ft	0.0 to 7.2 ft POORLY GRADED GRAVEL WITH CLAY AND SAND: About 60% coarse to fine, hard, subangular gravel; about 30% predominantly fine sand; about 10% fines with medium plasticity, high dry strength, medium toughness; maximum size, 75 mm; moist, tan; hard to auger; weak reaction with HCl.			

REMARKS

GPO [illegible]

1/ Report to nearest 0.1 foot

Figure 11-9. Coarse-grained soils with dual symbols.



Sheet 1 of 2

7-1336 A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO ____________

FEATURE ____________
AREA DESIGNATION ____________
COORDINATES N ____________ E ____________
APPROXIMATE DIMENSIONS ____________
DEPTH WATER ENCOUNTERED 1/ ____________ DATE ____________

PROJECT ____________
GROUND ELEVATION ____________
METHOD OF EXPLORATION ____________
LOGGED BY ____________
DATE(S) LOGGED ____________

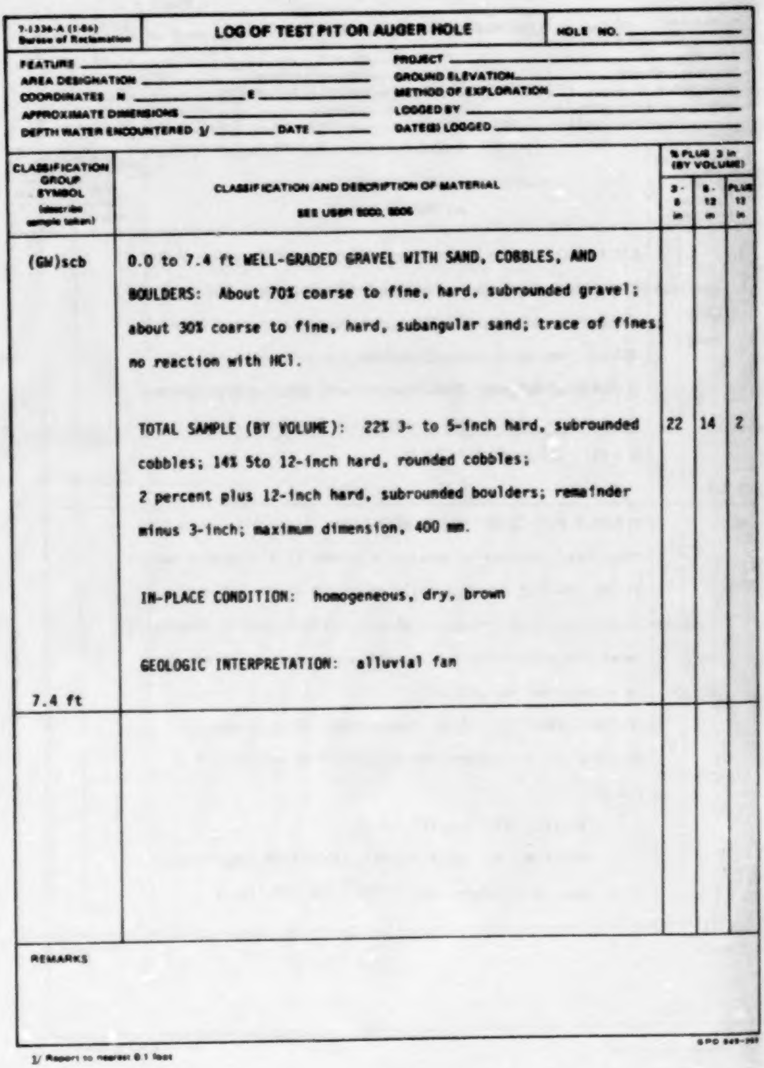
CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME)		
		3-5 in	5-12 in	PLUS 12 in
CL in-place unit weight 4.3 ft	0.0 to 4.3 ft LEAN CLAY: About 90% fines with medium plasticity, high dry strength, medium toughness; about 10% predominantly fine sand; maximum size, coarse sand; no reaction with HCl. IN-PLACE CONDITION: Firm, homogeneous, moist, reddish-brown In-place dry unit weight and moisture from test at 3.0 to 3.7 ft: 112.0 lbf/ft³, 11.7%.			
GC in-place unit weight 8.2 ft	4.3 to 8.2 ft CLAYEY GRAVEL WITH SAND: About 55% coarse to fine, hard, angular to subangular gravel (1/4 of gravel particles are flat or elongated); about 25% fines with medium plasticity, no dilatancy, high dry strength, medium toughness; about 20% predominantly fine sand; maximum size, 75 mm; weak to strong reaction with HCl. IN-PLACE CONDITION: Firm, homogeneous, moist, brown In-place dry unit weight and moisture from test at 6.2 to 7.0 ft Total: 129.7 lbf/ft³, 13.2% Minus No. 4: 107.8 lbf/ft³, 12.1% (90% compaction) Max. Unit Weight, Opt.: 119.7 lbf/ft³, 11.0%			

REMARKS

GPO [illegible]

1/ Report to nearest 0.1 foot

Figure 11-10. Reporting in-place unit weight tests and percent compaction.



7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. ______

FEATURE ______
AREA DESIGNATION ______
COORDINATES N ______ E ______
APPROXIMATE DIMENSIONS ______
DEPTH WATER ENCOUNTERED 1/ ______ DATE ______
PROJECT ______
GROUND ELEVATION ______
METHOD OF EXPLORATION ______
LOGGED BY ______
DATE(S) LOGGED ______

CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME)		
		3-5 in	5-12 in	PLUS 12 in
(GW)scb 7.4 ft	0.0 to 7.4 ft WELL-GRADED GRAVEL WITH SAND, COBBLES, AND BOULDERS: About 70% coarse to fine, hard, subrounded gravel; about 30% coarse to fine, hard, subangular sand; trace of fines; no reaction with HCl. TOTAL SAMPLE (BY VOLUME): 22% 3- to 5-inch hard, subrounded cobbles; 14% 5to 12-inch hard, rounded cobbles; 2 percent plus 12-inch hard, subrounded boulders; remainder minus 3-inch; maximum dimension, 400 mm. IN-PLACE CONDITION: homogeneous, dry, brown GEOLOGIC INTERPRETATION: alluvial fan	22	14	2

REMARKS

GPO [illegible]

1/ Report to nearest 0.1 foot

Figure 11-11. Soil with measured percentages of cobbles and boulders.

Coarse sand
5-mm increments from 5 mm to 50 mm
25-mm increments from 50 mm to 300 mm
10-mm increments over 300 mm

for example: "maximum particle size 35 mm"
"maximum particle size 400 mm"

Format of Word Descriptions for Test Pits and Auger Hole Logs

General Instructions

The following subsections provide general instructions for log format and descriptions. Refer to Chapter 3 for descriptive criteria, classification, and group names and symbols.

- Capitalize the group name. If cobbles and boulders are present, include them in the typical name.

- Describe plasticity of fines as:

  "approx. 30% fines with high plasticity"
  "approx. 60% fines with low to medium plasticity"
  "approx. 10% nonplastic fines"

- Give results of hand tests when performed.

- Use "reaction with HCl."

- Do not give unnecessary information such as, "no toughness," "no odor," "no gravel," and "no fines."

However, the negative result of a hand test is positive information. These are to be reported as, "no dilatancy," "nonplastic," "no dry strength," or "no reaction with HCl."

Table 11-1 is a checklist for descriptors to be provided and the proper format. Discussions of the format for description, laboratory results, and other descriptive information are presented in the following subsections.

Table 11-1. – Checklist for the description of soils in test pit and auger hole logs.

1. Group symbol. – Capitalized and shown in the left-hand column.
2. Depth. – Depths of interval classified, shown as either meters or feet and tenths of units in second column from the left.
3. Identification of sample. – Type and size of sample and origin of sample shown in third column from the left.
4. Classification and description column. –
    a. First paragraph. –
        (1) Depth of interval classified
        (2) Group name – capitalized
        (3) Percent of fines sand and gravel by weight (include trace amounts but not added to percentage which must equal 100 percent)
        (4) Description of particles
            (a) Particle size range: describe as either gravel – fine or coarse, and/or sand – fine, medium, or coarse
            (b) Hardness of particles (coarse sand and larger)
            (c) Particle angularity (angular, subangular, subrounded, or rounded)
            (d) Particle shape (flat, elongated, or flat and elongated)
            (e) Maximum particle size or dimension
        (5) Description of fines
            (a) Plasticity (nonplastic, low, medium, or high)
            (b) Dilatancy (none, slow, or rapid)
            (c) Dry strength (none, low, medium, high, or very high)
            (d) Toughness (low, medium, or high)
        (6) Moisture condition (dry, moist, or wet)
        (7) Color (wet color)
        (8) Odor (mention only if organic or unusual)
        (9) Reaction with HCl (none, weak, or strong)
    b. TOTAL SAMPLE (BY VOLUME): second paragraph, if applicable – more than 50 percent plus 75-mm material
        (1) Percent of cobbles and/or boulders
        (2) Same information as item 4.a (4)
    c. IN-PLACE CONDITION: third paragraph (second

Table 11-1. – Checklist for the description of soils in test pit and auger hole logs.—Continued

paragraph if less than 50 percent oversize)
 (1) Consistency – fine-grained soils only (very soft, soft, firm, hard, or very hard)
 (2) Structure (stratified, lensed)
 (3) Moisture (if an in-place condition paragraph is included moisture is not described in the first paragraph)
 (4) Color (if an in-place condition paragraph is included, color is not described in the first paragraph)
 (5) Result of in-place density and/or moisture tests
d. GEOLOGIC INTERPRETATION: (fourth paragraph) geologic age and stratigraphic name if known or genetic name. Local name, if any, may be provided also.
5. Remarks block. – Provide additional description or remarks such as root holes, other debris found, caving, degree of difficulty to auger or excavate, reason for refusal or reached predetermined depth, and water-level information or hole completion.

Reporting by Method of Classification

Preparation of Logs Based on Visual Classification.—List percentages of fines, sand and gravel in descending order of percent (must add up to 100 percent). For visual classification, estimate percentages to the closest 5 percent. Precede the estimated percentages with "approx.", not "about." If a component is present but is less than 5 percent of the total, use "trace" for 1 to 3 percent. "Trace" is not included in the 100 percent.

Preparation of Logs Based on Laboratory Classification.—When logs are prepared using laboratory classifications (based on laboratory tests), the information must be presented on the log as shown in figure 11-4. The difference between a laboratory and a visual classification will be designated by an asterisk that refers to a note on each log sheet.

The field visual classification must not be changed, nor must the estimated percentages, plasticity description, and the results of the hand tests (dry strength, dilatancy, and toughness) be changed to reflect laboratory tests results. The visual classification is based on the total material observed; whereas, the laboratory classification is based on a representative sample of the material.

The specimens for testing are to be from samples that represent the entire interval being described (see designation E-2 in the *Earth Manual* [4]). The material collected must be split or quartered to obtain the specimen that is to be tested in the laboratory.

Coefficients of uniformity and curvature (C_u and C_c) are to be calculated and reported on the logs for coarse-grained materials containing 12 percent or less fines.

Laboratory gradation percentages and Atterberg limits are to be reported to the nearest whole number.

Procedures for Reporting Laboratory Data in Addition to Visual Classification and Description.—In some instances, gradation analyses and Atterberg limits tests are performed on soil samples in conjunction with preparation of logs of test pits or auger holes. These data should be shown on the logs and clearly identified as laboratory test data. If tests are performed for reasons other than preparation of the log, they should not be reported as part of the log.

Specimens for testing are to be from samples that represent the entire interval being described. If this is not possible, the location of the sample must be given as part of the word description. The sample taken must be split or quartered to get the specimen size required for testing (fig. 11-5, interval 0.0 to 2.9 m.).

Laboratory test data are to be presented in a separate paragraph. If the test results indicate a different classification, and therefore different group symbol and/or group name than the visual classification, give the laboratory classification symbol and name in this paragraph (fig. 11-6).

Note: For logs which incorporate the results of laboratory test, the statement "Classification by laboratory tests" should be placed in the "Remarks" portion of the log.

Coefficients of uniformity and curvature (C_u and C_c) are to be calculated and reported on the logs for coarse-grained materials containing 12 percent or less fines.

All laboratory gradation percentages and Atterberg limits are to be reported to the nearest whole number.

Reporting Undisturbed (In-place) Conditions

List in-place conditions on logs of test pits in a separate paragraph (fig. 11-7). Do not give in-place soil conditions (consistency, compactness) on auger hole logs (unless the holes are large enough to inspect). Instead, describe difficulty of augering (fig. 11-8). Also describe caving or any other unusual occurrence during drilling of the auger hole.

In-place density tests often are performed in test pits or trenches. When a large quantity of logs are reviewed, the availability of the density information on the log can save time, even though additional time is required for preparation of the log. Adding data also might prevent it from being overlooked.

Results of in-place density tests that are performed in test pits or trenches are to be included in the descriptive paragraph on in-place conditions on the log, as illustrated in figure 11-10.

Results of any laboratory compaction tests (Proctor, minimum and/or maximum density) performed on the material from the in-place density tests or from the pit or trench are to be included on the log.

For pipeline investigations, the percent of the maximum laboratory dry unit weight or the percent relative unit weight are to be shown in parentheses on the logs (fig. 11-10).

Unit weights are to be reported to the nearest 0.1 lb/ft^3 or 1 kg/m^3. Moisture content is to be reported to the nearest 0.1 percent. Percent of laboratory maximum dry unit weight or percent relative unit weight is to be reported to the nearest whole number.

Geologic Interpretation

Geologic interpretations should be made by or under the supervision of a geologist. Give geologic interpretation in a separate paragraph (fig. 11-7). Do not give geologic interpretation for earth dam borrow areas; however, factual geologic data may be presented. Although geologic interpretations are not permitted on earth dam borrow logs, interpretation may be included in the narrative section of the materials portion of the design data submittals.

Format of Word Descriptions on Test Pit and Auger Hole Logs for Soils with Cobbles and Boulders

If the soil has less than 50 percent cobbles and boulders (by volume), give the group name of the minus 75-mm portion and include cobbles and/or boulders in the group name (fig. 11-11). Use two paragraphs to describe soil (figs. 11-6 and 11-10). Refer to Chapter 3 for a more complete discussion of classification and classification group names and symbols.

- Describe the minus 75-mm fraction in the first paragraph. These component percentages are estimated by weight.

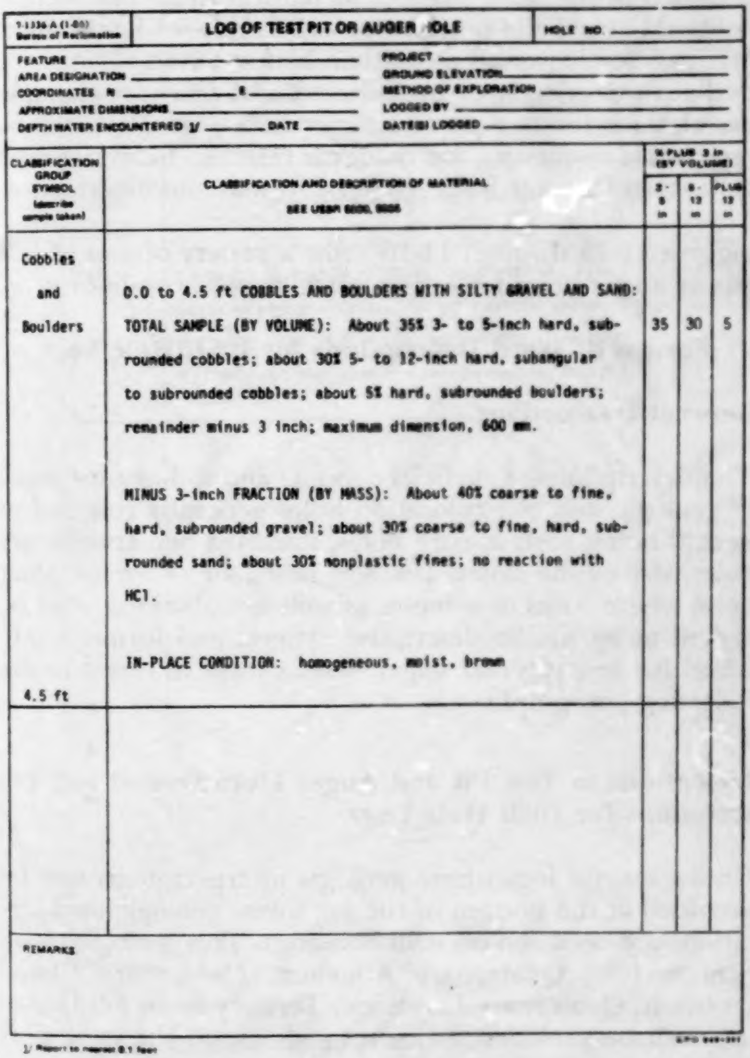
- Describe the total sample in a second paragraph. These percentages are estimated by volume. If the percentage of cobbles and boulders is determined by measurement, still use "approx." in the word description.

If the soil has more than 50 percent cobbles and boulders (by volume), list cobbles and boulders first in the name (fig. 11-12). Do not give a group symbol or group name.

- Describe the total sample in the first paragraph. Percentages are estimated by volume.

- Describe the minus 75-mm fraction in a second paragraph. Percentages are estimated by weight.

Angular particles larger than 75 mm in size are to be described as cobbles and boulders, not as rock fragments. A description of their shape should be provided in the word description.



7-1336 A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. ____________

FEATURE ____________
AREA DESIGNATION ____________
COORDINATES N ________ E ________
APPROXIMATE DIMENSIONS ____________
DEPTH WATER ENCOUNTERED 1/ ________ DATE ________
PROJECT ____________
GROUND ELEVATION ____________
METHOD OF EXPLORATION ____________
LOGGED BY ____________
DATE(S) LOGGED ____________

CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME)		
		3-5 in	5-12 in	PLUS 12 in
Cobbles and Boulders	0.0 to 4.5 ft COBBLES AND BOULDERS WITH SILTY GRAVEL AND SAND:			
	TOTAL SAMPLE (BY VOLUME): About 35% 3- to 5-inch hard, subrounded cobbles; about 30% 5- to 12-inch hard, subangular to subrounded cobbles; about 5% hard, subrounded boulders; remainder minus 3 inch; maximum dimension, 600 mm.	35	30	5
	MINUS 3-inch FRACTION (BY MASS): About 40% coarse to fine, hard, subrounded gravel; about 30% coarse to fine, hard, subrounded sand; about 30% nonplastic fines; no reaction with HCl.			
4.5 ft	IN-PLACE CONDITION: homogeneous, moist, brown			

REMARKS

1/ Report to nearest 0.1 foot

Figure 11-12. Soil with more than 50 percent cobbles and boulders.

Description of Materials Other than Natural Soils

Materials which are not natural soils are not described or classified in the same manner as natural soils. The section entitled Use of Soil Classification as Secondary Identification Methods for Materials other than Natural Soils, Chapter 5, outlines the criteria to be followed and provides example descriptions for test pit and auger hole logs. Rather than repeat this discussion, the reader is referred to appropriate sections in Chapter 3 for example format and descriptions.

Figures 11-13 through 11-16 show a variety of logs of test pits or auger holes reflecting miscellaneous conditions.

Format of Word Descriptions for Drill Hole Logs

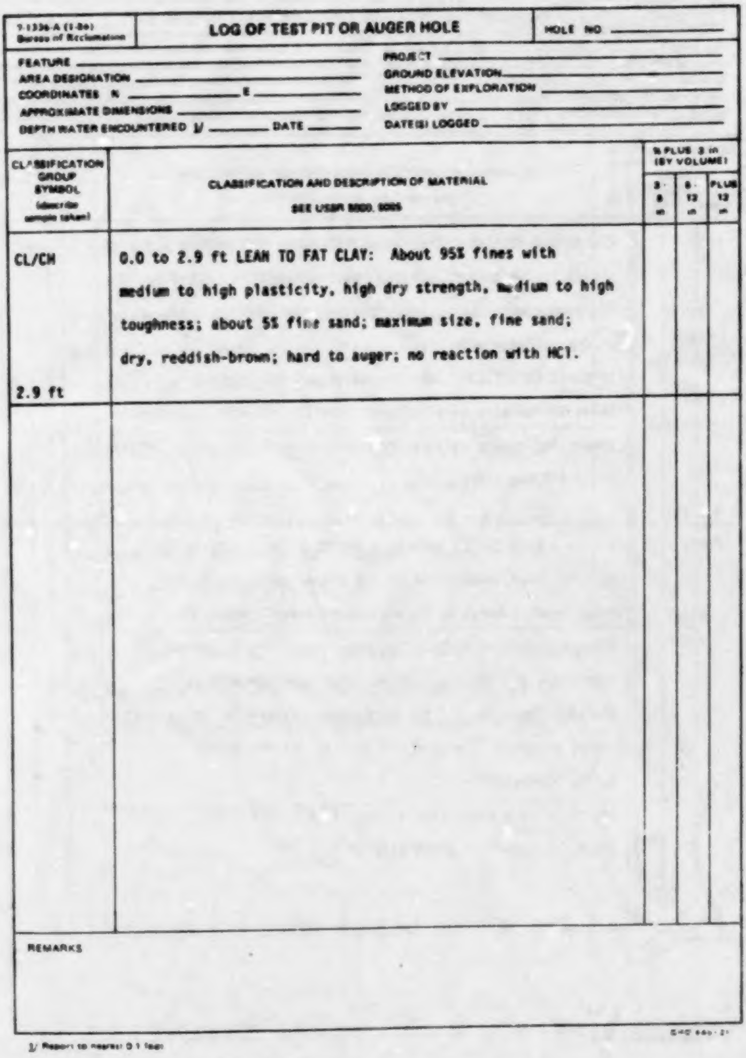
General Instructions

The descriptions of surficial deposits and soil-like materials in geologic logs of exploration holes generally referred to as drill holes, such as core holes, standard penetration test holes, drive-tube holes, Denison holes, or other sampling holes where cores or samples of soils are obtained, shall be logged using similar descriptive criteria and format established for test pits and auger holes except as noted in the following paragraphs.

Exceptions to Test Pit and Auger Hole Format and Descriptions for Drill Hole Logs

Unlike test pit logs where geologic interpretations may be provided at the bottom of the log form, geologic interpretations are required on drill hole logs. The geologic classification (i.e., Quaternary Alluvium, Quaternary Glacial Outwash, Quaternary Landslide, Tertiary Basin Fill Deposits) shall be provided as main headings on the geological drill hole log.

Group names are to be capitalized in all test pit and auger hole logs. Where capitalization of the group name would conflict with main headings on drill hole logs, only the first letter of each word in the group name and the letters in the group symbol (GP) need be capitalized. If the first letter of



7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO ________

FEATURE ________
AREA DESIGNATION ________
COORDINATES N ________ E ________
APPROXIMATE DIMENSIONS ________
DEPTH WATER ENCOUNTERED 1/ ________ DATE ________
PROJECT ________
GROUND ELEVATION ________
METHOD OF EXPLORATION ________
LOGGED BY ________
DATE(S) LOGGED ________

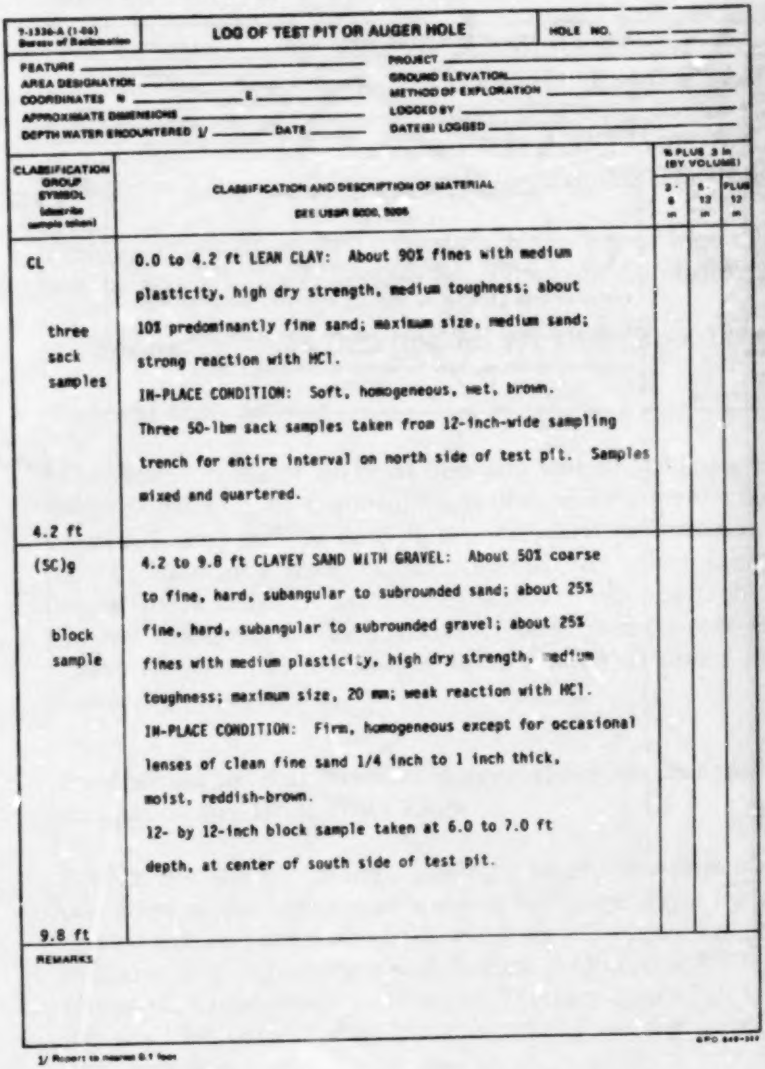
CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME)		
		3-5 in	5-12 in	PLUS 12 in
CL/CH 2.9 ft	0.0 to 2.9 ft LEAN TO FAT CLAY: About 95% fines with medium to high plasticity, high dry strength, medium to high toughness; about 5% fine sand; maximum size, fine sand; dry, reddish-brown; hard to auger; no reaction with HCl.			

REMARKS

GPO [illegible]

1/ Report to nearest 0.1 foot

Figure 11-13. Borderline soils.



7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. ____

FEATURE ____
AREA DESIGNATION ____
COORDINATES N ____ E ____
APPROXIMATE DIMENSIONS ____
DEPTH WATER ENCOUNTERED 1/ ____ DATE ____

PROJECT ____
GROUND ELEVATION ____
METHOD OF EXPLORATION ____
LOGGED BY ____
DATE(S) LOGGED ____

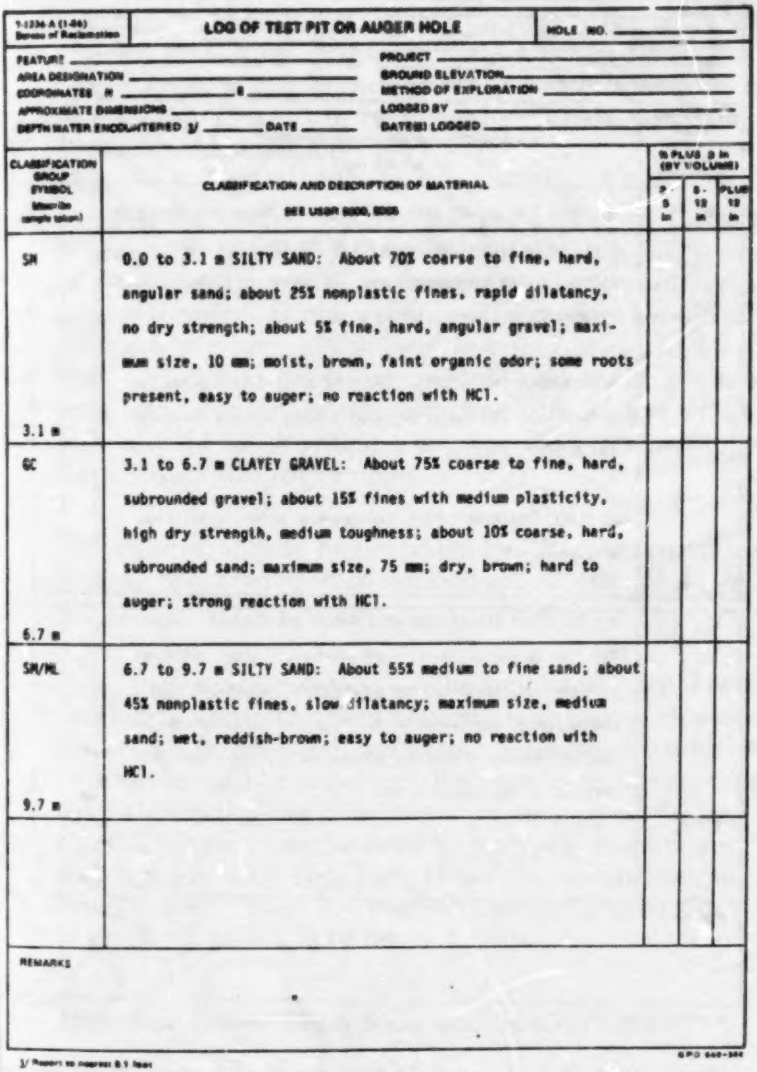
CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME)		
		3 - 6 in	6 - 12 in	PLUS 12 in
CL three sack samples 4.2 ft	0.0 to 4.2 ft LEAN CLAY: About 90% fines with medium plasticity, high dry strength, medium toughness; about 10% predominantly fine sand; maximum size, medium sand; strong reaction with HCl. IN-PLACE CONDITION: Soft, homogeneous, wet, brown. Three 50-lbm sack samples taken from 12-inch-wide sampling trench for entire interval on north side of test pit. Samples mixed and quartered.			
(SC)g block sample 9.8 ft	4.2 to 9.8 ft CLAYEY SAND WITH GRAVEL: About 50% coarse to fine, hard, subangular to subrounded sand; about 25% fine, hard, subangular to subrounded gravel; about 25% fines with medium plasticity, high dry strength, medium toughness; maximum size, 20 mm; weak reaction with HCl. IN-PLACE CONDITION: Firm, homogeneous except for occasional lenses of clean fine sand 1/4 inch to 1 inch thick, moist, reddish-brown. 12- by 12-inch block sample taken at 6.0 to 7.0 ft depth, at center of south side of test pit.			

REMARKS

GPO [illegible]

1/ Report to nearest 0.1 foot

Figure 11-14. Test pit with samples taken.



7-1336 A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. ______

FEATURE ______
AREA DESIGNATION ______
COORDINATES N ______ E ______
APPROXIMATE DIMENSIONS ______
DEPTH WATER ENCOUNTERED 1/ ______ DATE ______
PROJECT ______
GROUND ELEVATION ______
METHOD OF EXPLORATION ______
LOGGED BY ______
DATE(S) LOGGED ______

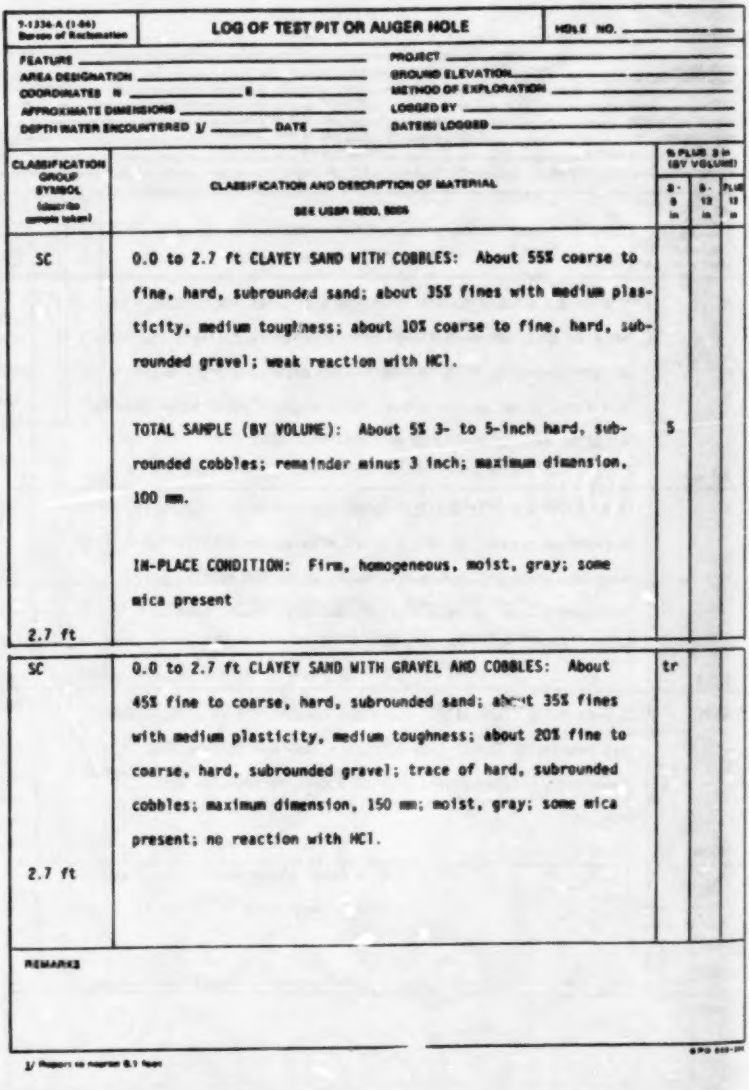
CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME)		
		3-5 in	5-12 in	PLUS 12 in
SM 3.1 m	0.0 to 3.1 m SILTY SAND: About 70% coarse to fine, hard, angular sand; about 25% nonplastic fines, rapid dilatancy, no dry strength; about 5% fine, hard, angular gravel; maximum size, 10 mm; moist, brown, faint organic odor; some roots present, easy to auger; no reaction with HCl.			
GC 6.7 m	3.1 to 6.7 m CLAYEY GRAVEL: About 75% coarse to fine, hard, subrounded gravel; about 15% fines with medium plasticity, high dry strength, medium toughness; about 10% coarse, hard, subrounded sand; maximum size, 75 mm; dry, brown; hard to auger; strong reaction with HCl.			
SM/ML 9.7 m	6.7 to 9.7 m SILTY SAND: About 55% medium to fine sand; about 45% nonplastic fines, slow dilatancy; maximum size, medium sand; wet, reddish-brown; easy to auger; no reaction with HCl.			

REMARKS

1/ Report to nearest 0.1 foot

GPO 840-386

Figure 11-15. Disturbed samples.



7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. ______

FEATURE ______
AREA DESIGNATION ______
COORDINATES N ______ E ______
APPROXIMATE DIMENSIONS ______
DEPTH WATER ENCOUNTERED 1/ ______ DATE ______
PROJECT ______
GROUND ELEVATION ______
METHOD OF EXPLORATION ______
LOGGED BY ______
DATE(S) LOGGED ______

CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME)		
		3-5 in	5-12 in	PLUS 12 in
SC	0.0 to 2.7 ft CLAYEY SAND WITH COBBLES: About 55% coarse to fine, hard, subrounded sand; about 35% fines with medium plasticity, medium toughness; about 10% coarse to fine, hard, subrounded gravel; weak reaction with HCl.			
	TOTAL SAMPLE (BY VOLUME): About 5% 3- to 5-inch hard, subrounded cobbles; remainder minus 3 inch; maximum dimension, 100 mm.	5		
	IN-PLACE CONDITION: Firm, homogeneous, moist, gray; some mica present			
2.7 ft				
SC	0.0 to 2.7 ft CLAYEY SAND WITH GRAVEL AND COBBLES: About 45% fine to coarse, hard, subrounded sand; about 35% fines with medium plasticity, medium toughness; about 20% fine to coarse, hard, subrounded gravel; trace of hard, subrounded cobbles; maximum dimension, 150 mm; moist, gray; some mica present; no reaction with HCl.	tr		
2.7 ft				

REMARKS

1/ Report to nearest 0.1 foot

Figure 11-16. Two descriptions from the same horizon. (Top) Undisturbed soil containing estimated percent of cobbles and/or boulders. (Bottom) Disturbed soil containing trace of cobbles.

each word is not capitalized, the group name is considered informal usage only and not a classification.

Classification and word description format for drill hole logs is similar to those used for test pit logs. Also, materials recovered from drill holes are generally considered to represent in-place conditions. Exceptions to these criteria are where samples are not recovered or where poor recovery precludes classification (fig. 11-17).

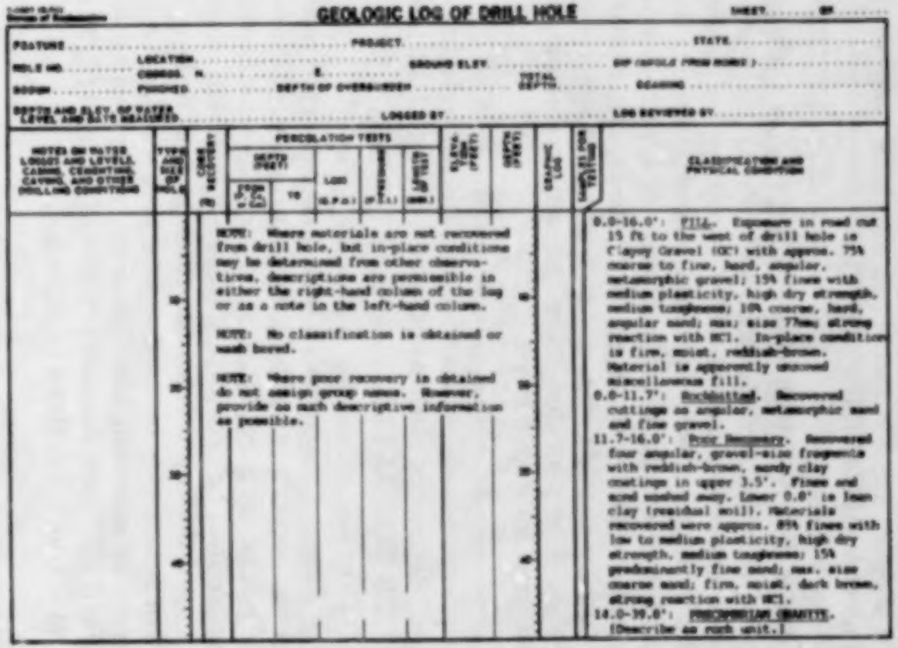
Samples Recovered from Wash Borings or as Cuttings.—Where drill holes are advanced with a rock bit, water jet, or other nonsampling methods, a group symbol and name or classification of the recovered materials should not be assigned, nor should in-place descriptions, such as consistency and compactness, be used. However, descriptive criteria such as particle size, dry strength, and reaction with HCl, should be provided using the same terminology and format used for auger holes.

Descriptions should be preceded by "Recovered cuttings as . . ." or "Recovered wash samples as . . ." (fig. 11-17, interval 0.0-11.7 ft [0 to 3.57 m]).

Poor or Partial Recovery.—Where poor or partial recovery precludes accurate classification, a primary classification should not be assigned, but as much descriptive information as possible shall be provided. Recovered materials, together with known drilling conditions, cuttings, and drilling fluid colors or losses, may be used to interpret reasons for losses and types of materials lost. However, an appropriate subheading (i.e., "Poor Recovery") should be used (fig. 11-18, interval 2.1 to 3.9 ft [0.64 to 1.2m]).

Materials Other Than Soils and Special Cases

As discussed previously in Chapter 3, "Use of Soil Classification as Secondary Identification Methods for Materials Other Than Natural Soils," exceptions to the test pit and auger hole classification and format are also applicable to drill hole logs. These special cases include processed or manmade materials, shells, partially lithified or poorly cemented



GEOLOGIC LOG OF DRILL HOLE SHEET ...... OF ......

FEATURE .... PROJECT .... STATE ....
HOLE NO. ...... LOCATION .... COORDS. N. ...... E. ...... GROUND ELEV. ...... DIP (ANGLE FROM HORIZ.) ......
BEGUN ...... FINISHED ...... DEPTH OF OVERBURDEN ...... TOTAL DEPTH ...... BEARING ......
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED ...... LOGGED BY ...... LOG REVIEWED BY ......

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS | PERCOLATION TESTS | CLASSIFICATION AND PHYSICAL CONDITION

10 — 20 — 30 — 40

NOTE: Where materials are not recovered from drill hole, but in-place conditions may be determined from other observations, descriptions are permissible in either the right-hand column of the log or as a note in the left-hand column.

NOTE: No classification is obtained or wash bored.

NOTE: Where poor recovery is obtained do not assign group names. However, provide as much descriptive information as possible.

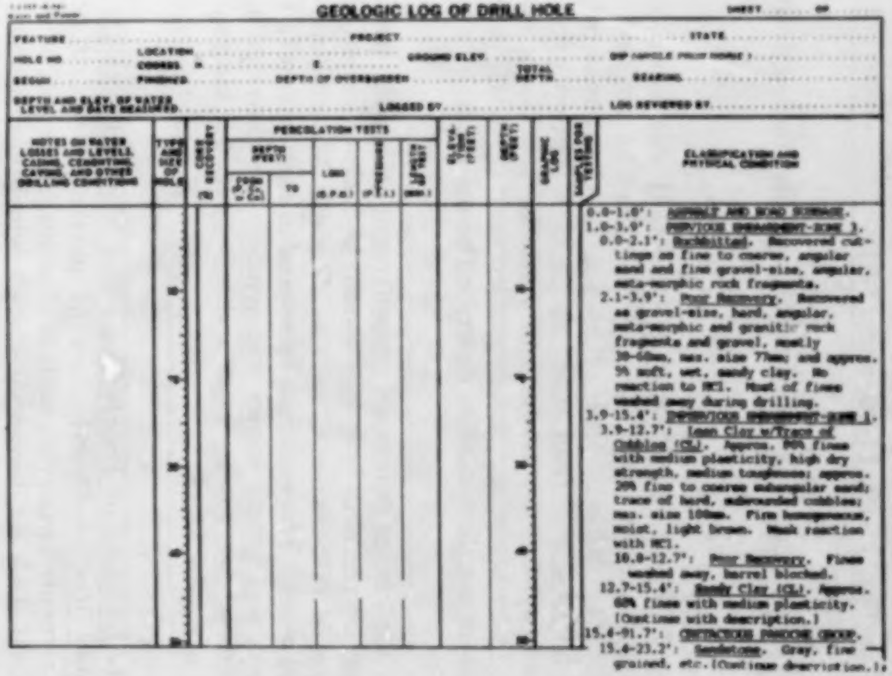
0.0-16.0': FILL. Exposure in road cut 15 ft to the west of drill hole is Clayey Gravel (GC) with approx. 75% coarse to fine, hard, angular, metamorphic gravel; 15% fines with medium plasticity, high dry strength, medium toughness; 10% coarse, hard, angular sand; max. size 75mm; strong reaction with HCl. In-place condition is firm, moist, reddish-brown. Material is apparently unsorted miscellaneous fill.

0.0-11.7': Rockbitted. Recovered cuttings as angular, metamorphic sand and fine gravel.

11.7-16.0': Poor Recovery. Recovered four angular, gravel-size fragments with reddish-brown, sandy clay coatings in upper 3.5'. Fines and sand washed away. Lower 0.8' is lean clay (residual soil). Materials recovered were approx. 85% fines with low to medium plasticity, high dry strength, medium toughness; 15% predominantly fine sand; max. size coarse sand; firm, moist, dark brown, strong reaction with HCl.

16.0-39.0': PRECAMBRIAN GRANITE. [Describe as rock unit.]

Figure 11-17. Drill hole advanced with tri-cone roller rock.



GEOLOGIC LOG OF DRILL HOLE

SHEET .... OF ....

FEATURE .... PROJECT .... STATE ....

HOLE NO. .... LOCATION .... COORDS. N .... E .... GROUND ELEV. .... DIP (ANGLE FROM HORIZ.) ....

BEGUN .... FINISHED .... DEPTH OF OVERBURDEN .... TOTAL DEPTH .... BEARING ....

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED .... LOGGED BY .... LOG REVIEWED BY ....

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS					ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
			DEPTH (FEET)		LOSS	PRESSURE	TIME					
			FROM	TO	(G.P.M.)	(P.S.I.)	(MIN.)					
												0.0-1.0': ASPHALT AND ROAD SURFACE. 1.0-3.9': PERVIOUS EMBANKMENT-ZONE 3. 0.0-2.1': Backfilled. Recovered cuttings as fine to coarse, angular sand and fine gravel-size, angular, meta-morphic rock fragments. 2.1-3.9': Poor Recovery. Recovered as gravel-size, hard, angular, meta-morphic and granitic rock fragments and gravel, mostly 30-60mm, max. size 75mm; and approx. 5% soft, wet, sandy clay. No reaction to HCl. Most of fines washed away during drilling. 3.9-15.4': IMPERVIOUS EMBANKMENT-ZONE 1. 3.9-12.7': Lean Clay w/Trace of Cobbles (CL). Approx. 80% fines with medium plasticity, high dry strength, medium toughness; approx. 20% fine to coarse subangular sand; trace of hard, subrounded cobbles; max. size 100mm. Firm homogeneous, moist, light brown. Weak reaction with HCl. 10.0-12.7': Poor Recovery. Fines washed away, barrel blocked. 12.7-15.4': Sandy Clay (CL). Approx. 60% fines with medium plasticity. (Continue with description.) 15.4-91.7': CRETACEOUS PANOCHE GROUP. 15.4-23.2': Sandstone. Gray, fine grained, etc. (Continue description.)

Figure 11-18. Log showing poor recovery.

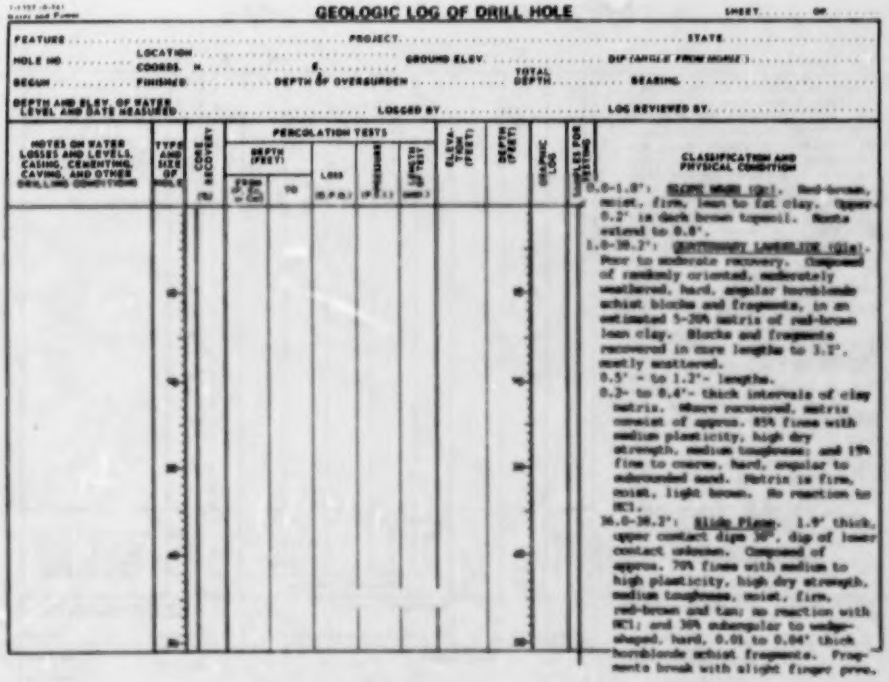
materials and decomposed bedrock, and shallow surficial deposits or soils. In addition to these special cases, for purposes of drill hole logging, there are two other special categories where soil-like materials are not classified by USBR 5000 (Unified Soil Classification System). These are soil-like slide-failure zones or planes; shear or fault zones; bedrock units which are recovered as soil-like material; and landslides and talus (figs. 11-19, 11-20, and 11-21).

Format and classification for these exceptions are described below.

Processed or Manmade Materials.—Surficial deposits such as tailings, crushed rock, shells, or slag shall be assigned a genetic name such as filter, bedding, or drain material, shells, tailings, and road base, and a classification group name and symbol are assigned in quotation marks, for example: Filter material, "poorly graded sand (SP-SM)." Soil descriptors are then used to describe the materials.

Where drill holes penetrate embankment materials, main headings on the drill hole logs should be a classification of the type of embankment, such as "Zone 3 Miscellaneous Embankment." The materials recovered in each interval are classified, and group names and symbols are provided as subheadings. See 1.0- to 3.9-ft and 3.9- to 15.4-ft intervals shown in figure 11-18.

Partially Lithified or Poorly Cemented Materials and Decomposed Rock.—Descriptions of partially lithified or poorly cemented materials such as siltstone, claystone, sandstone, and shale or decomposed rock which are disaggregated during drilling or field classification testing shall be classified by an appropriate rock unit name or by geologic formation name, if known, of the in situ materials and then described using descriptors for rock (Chap. 4). A classification for the disaggregated materials should be reported in quotation marks on the drill logs and all figures, tables, drawings, or narrative descriptions. The disaggregation mechanism (i.e., drilling or testing) shall be specified (fig. 11-21, interval 17.3 to 67.9 ft).



GEOLOGIC LOG OF DRILL HOLE

SHEET .... OF ....

FEATURE .... PROJECT .... STATE ....

HOLE NO. .... LOCATION .... GROUND ELEV. .... DIP (ANGLE FROM HORIZ.) ....

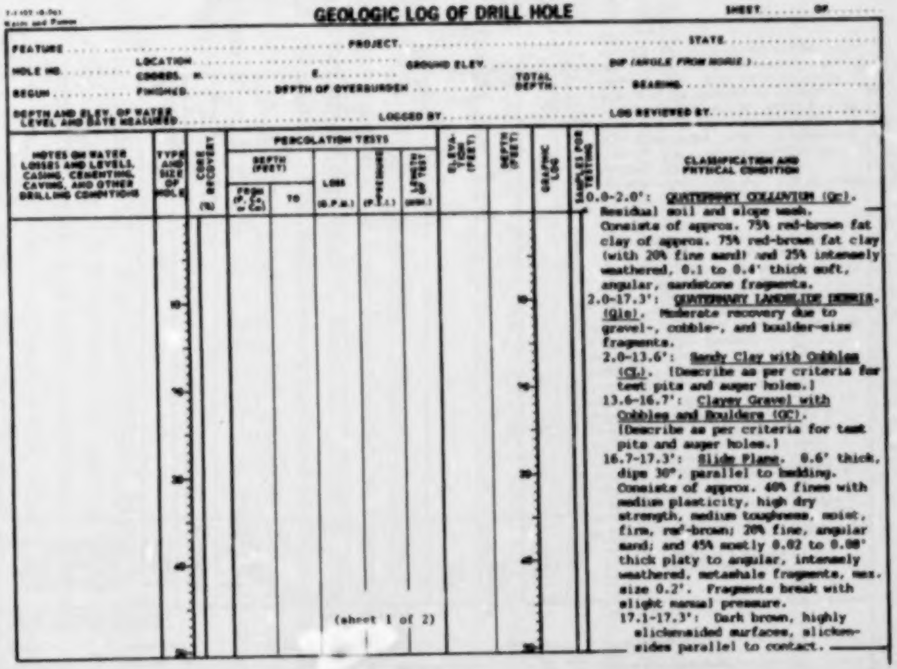
COORDS. N. .... E. ....

BEGUN .... FINISHED .... DEPTH OF OVERBURDEN .... TOTAL DEPTH .... BEARING ....

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED .... LOGGED BY .... LOG REVIEWED BY ....

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS: DEPTH (FEET) FROM	PERCOLATION TESTS: DEPTH (FEET) TO	PERCOLATION TESTS: LOSS (G.P.M.)	PERCOLATION TESTS: PRESSURE (P.S.I.)	PERCOLATION TESTS: LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
												0.0-1.0': SLOPE WASH (Qsw). Red-brown, moist, firm, lean to fat clay. Upper 0.2' is dark brown topsoil. Roots extend to 0.8'. 1.0-38.2': QUATERNARY LANDSLIDE (Qls). Poor to moderate recovery. Composed of randomly oriented, moderately weathered, hard, angular hornblende schist blocks and fragments, in an estimated 5-20% matrix of red-brown lean clay. Blocks and fragments recovered in core lengths to 3.2', mostly scattered. 0.5' - to 1.2'- lengths. 0.2- to 0.4'- thick intervals of clay matrix. Where recovered, matrix consist of approx. 85% fines with medium plasticity, high dry strength, medium toughness; and 15% fine to coarse, hard, angular to subrounded sand. Matrix is firm, moist, light brown. No reaction to HCl. 36.0-38.2': Slide Plane. 1.9' thick, upper contact dips 30°, dip of lower contact unknown. Composed of approx. 70% fines with medium to high plasticity, high dry strength, medium toughness, moist, firm, red-brown and tan; no reaction with HCl; and 30% subangular to wedge-shaped, hard, 0.01 to 0.04' thick hornblende schist fragments. Fragments break with slight finger pres.

Figure 11-19. Log of landslide material (a).



GEOLOGIC LOG OF DRILL HOLE

SHEET ...... OF ......

FEATURE ...... PROJECT ...... STATE ......

HOLE NO. ...... LOCATION ...... COORDS. N. ...... E. ...... GROUND ELEV. ...... DIP (ANGLE FROM HORIZ.) ......

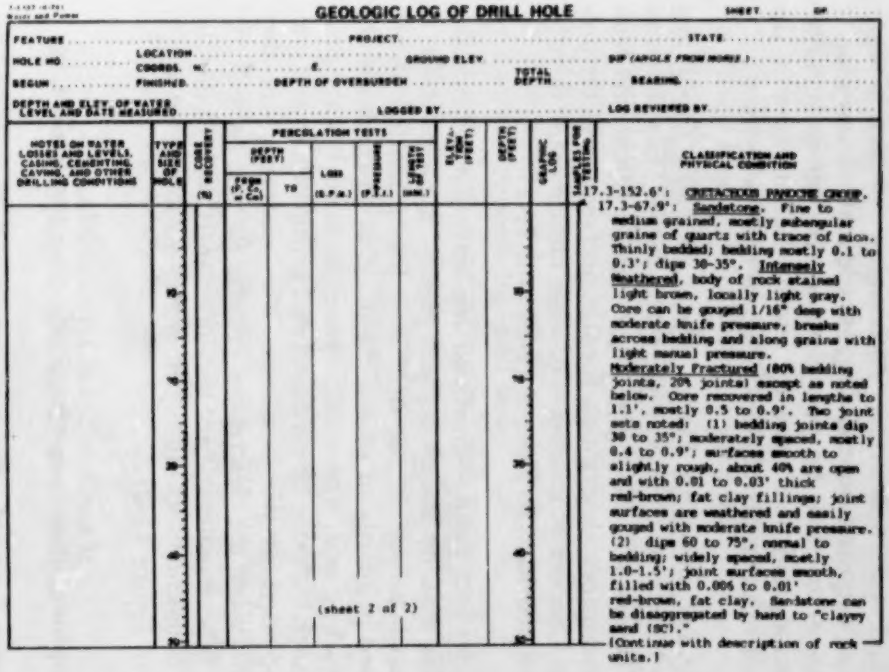
BEGUN ...... FINISHED ...... DEPTH OF OVERBURDEN ...... TOTAL DEPTH ...... BEARING ......

DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED ...... LOGGED BY ...... LOG REVIEWED BY ......

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS: DEPTH (FEET) FROM	TO	LOSS (G.P.M.)	PRESSURE (P.S.I.)	TIME (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
												0.0-2.0': QUATERNARY COLLUVIUM (Qc). Residual soil and slope wash. Consists of approx. 75% red-brown fat clay of approx. 75% red-brown fat clay (with 20% fine sand) and 25% intensely weathered, 0.1 to 0.4' thick soft, angular, sandstone fragments. 2.0-17.3': QUATERNARY LANDSLIDE DEBRIS (Qls). Moderate recovery due to gravel-, cobble-, and boulder-size fragments. 2.0-13.6': Sandy Clay with Cobbles (CL). [Describe as per criteria for test pits and auger holes.] 13.6-16.7': Clayey Gravel with Cobbles and Boulders (GC). [Describe as per criteria for test pits and auger holes.] 16.7-17.3': Slide Plane. 0.6' thick, dips 30°, parallel to bedding. Consists of approx. 40% fines with medium plasticity, high dry strength, medium toughness, moist, firm, red-brown; 20% fine, angular sand; and 45% mostly 0.02 to 0.08' thick platy to angular, intensely weathered, metashale fragments, max. size 0.2'. Fragments break with slight manual pressure. 17.1-17.3': Dark brown, highly slickensided surfaces, slickensides parallel to contact.

(sheet 1 of 2)

Figure 11-20. Log of landslide material (b).



GEOLOGIC LOG OF DRILL HOLE

SHEET .... OF ....

FEATURE .... PROJECT .... STATE ....
HOLE NO. .... LOCATION .... GROUND ELEV. .... DIP (ANGLE FROM HORIZ.) ....
COORDS. N. .... E. ....
BEGUN .... FINISHED .... DEPTH OF OVERBURDEN .... TOTAL DEPTH .... BEARING ....
DEPTH AND ELEV. OF WATER LEVEL AND DATE MEASURED .... LOGGED BY .... LOG REVIEWED BY ....

NOTES ON WATER LOSSES AND LEVELS, CASING, CEMENTING, CAVING, AND OTHER DRILLING CONDITIONS	TYPE AND SIZE OF HOLE	CORE RECOVERY (%)	PERCOLATION TESTS DEPTH (FEET) FROM (P, Co, or Ca)	PERCOLATION TESTS DEPTH (FEET) TO	PERCOLATION TESTS LOSS (G.P.M.)	PERCOLATION TESTS PRESSURE (P.S.I.)	PERCOLATION TESTS LENGTH OF TEST (MIN.)	ELEVATION (FEET)	DEPTH (FEET)	GRAPHIC LOG	SAMPLES FOR TESTING	CLASSIFICATION AND PHYSICAL CONDITION
				(sheet 2 of 2)								17.3-152.6': CRETACEOUS PANOCHE GROUP. 17.3-67.9': Sandstone. Fine to medium grained, mostly subangular grains of quartz with trace of mica. Thinly bedded; bedding mostly 0.1 to 0.3'; dips 30-35°. Intensely Weathered, body of rock stained light brown, locally light gray. Core can be gouged 1/16" deep with moderate knife pressure, breaks across bedding and along grains with light manual pressure. Moderately Fractured (80% bedding joints, 20% joints) except as noted below. Core recovered in lengths to 1.1', mostly 0.5 to 0.9'. Two joint sets noted: (1) bedding joints dip 30 to 35°; moderately spaced, mostly 0.4 to 0.9'; surfaces smooth to slightly rough, about 40% are open and with 0.01 to 0.03' thick red-brown; fat clay fillings; joint surfaces are weathered and easily gouged with moderate knife pressure. (2) dips 60 to 75°, normal to bedding; widely spaced, mostly 1.0-1.5'; joint surfaces smooth, filled with 0.006 to 0.01' red-brown, fat clay. Sandstone can be disaggregated by hand to "clayey sand (SC)." [Continue with description of rock units.]

Figure 11-21. Log of bedrock.

Shallow Surficial Deposits.—Surficial deposits such as drill pad or dozer trench fill for drill setups, shallow slope wash, or topsoil materials which will not be used in, or influence design or construction, may be classified by genetic classification (i.e., "fill,""Slope wash," or "topsoil"). Complete classification descriptions are not required on drill hole logs; however, a classification name and/or symbol may be assigned and is often desirable. Although a complete description is not required on each log, an adequate description of these materials shall be provided on the general legend, explanation, and note drawing and in the narrative of the report, if not completely described in drill hole logs.

Slide Failure Zones or Planes, Shear or Fault Zones, and Interbeds Recovered as Soil-like Materials.—These features should be described using geologic names. Shear and fault zone descriptors, description format, and examples are provided in Chapter 5. Examples of slide failure plane descriptions are provided in figures 11-20 and 11-21.

Landslides and Talus.—Surficial deposits such as landslides and talus shall be assigned their genetic geologic name in the main headings of the drill hole log. Landslide debris composed primarily of soils is classified as landslides in the main heading and, where differences in materials are present, materials should be classified and group names and symbols provided in the headings. The materials are then described using the descriptive criteria for test pit logs (fig. 11-20). Where materials are predominantly rock fragments, such as talus and block slides, the materials should be logged similar to figure 11-21.

Equipment Necessary for Preparing the Field Log

Equipment for performing the various field tests and describing the materials observed follows.

Required apparatus:

- Small supply of water (squirt bottle)—for performing field tests
- Pocket knife or small spatula
- Materials for taking or preserving samples—sacks, jars,

labels, cloth, wax, heater, etc.
- Hammer—for hardness descriptors
- Tape measure and/or rule (engineer's scale and metric scale)
- Small bottle of dilute hydrochloric acid [one part HCl (10 N) to three parts distilled water][1]/
- Rags for cleaning hands
- Log forms

Optional apparatus:

- Small test tube and stopper, or jar with lid
- Plastic bags for "calibration samples"
- Small hand lens
- Color identification charts (Munsel Color System)
- Paint brush and/or scrub brush and water for cleaning samples
- Marking pens
- Protractor
- Drillers' reports for drill holes
- Comparison samples (in jars): fine gravel—3/4 inch to No. 4 sieve; medium sand—No. 4 to No. 10 sieve; and coarse sand—No. 10 to No. 40 sieve
- Small Nos. 4 and 200 sieves

Example Descriptions and Format

The examples which follow are not all inclusive, but do serve to illustrate either the preferred or required format, description, organization, and some of the most significant exceptions to established standards.

Laboratory Classifications in Addition to Visual Classifications

In some instances, laboratory classifications may be determined in addition to the visual classification made in the field. This may be done to confirm the visual classification, particularly when starting work in a new location, or because the classification may be critical for some purpose.

---

[1]/When preparing the dilute HCl solution of one part concentrated hydrochloric acid (10 n) to three parts of distilled water, slowly add acid into water following necessary safety precautions. Handle with caution and store safely. If solution comes in contact with skin, rinse thoroughly with water.

The laboratory data used must be reported in a separate paragraph at the end of the work description as shown in the examples on the following page. If the laboratory classification is different than the visual classification, as in the upper example on the following page, give the group symbol in the left-hand column and the group name in the paragraph on the laboratory data.

DO NOT CHANGE THE VISUAL CLASSIFICATION OR DESCRIPTION. The visual classification is based on a widely observed area in the excavation, whereas the laboratory classification is based on a sample of the material. If the visual classification was the best judgment of an experienced classifier, both are correct in what they represent.

WORD DESCRIPTIONS FOR VARIOUS SOIL CLASSIFICATIONS

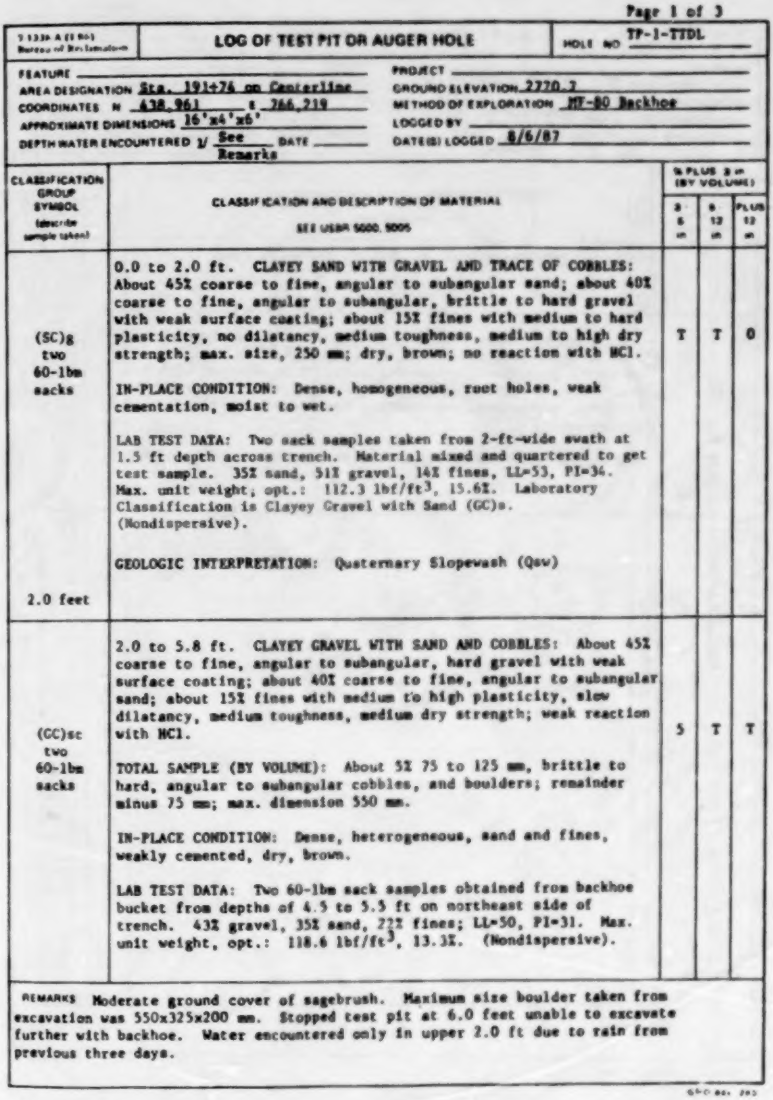
Figures 11-6 to 11-16 illustrate some typical word descriptions based on the soil classifications.

Logs generally are typed single spaced. The examples in this manual are presented double spaced for legibility.

Samples Taken

In addition to the brief description of the samples taken under the "classification group symbol" column, a more complete description of any samples taken from each depth interval is included in the word descriptions. The description should include the size of the sample, the location represented by the sample, and how the sample was obtained (e.g., quartering and splitting).

Examples of how to report the sample information for a test pit or trench are shown on figures 11-22 through 11-32.



Page 1 of 3

7-1336-A (1-86) Bureau of Reclamation	LOG OF TEST PIT OR AUGER HOLE	HOLE NO TP-1-TTDL

FEATURE ________

AREA DESIGNATION Sta. 191+76 on Centerline

COORDINATES N 438,961 E 266,219

APPROXIMATE DIMENSIONS 16'x4'x6'

DEPTH WATER ENCOUNTERED 1/ See Remarks DATE ________

PROJECT ________

GROUND ELEVATION 2770.3

METHOD OF EXPLORATION MF-80 Backhoe

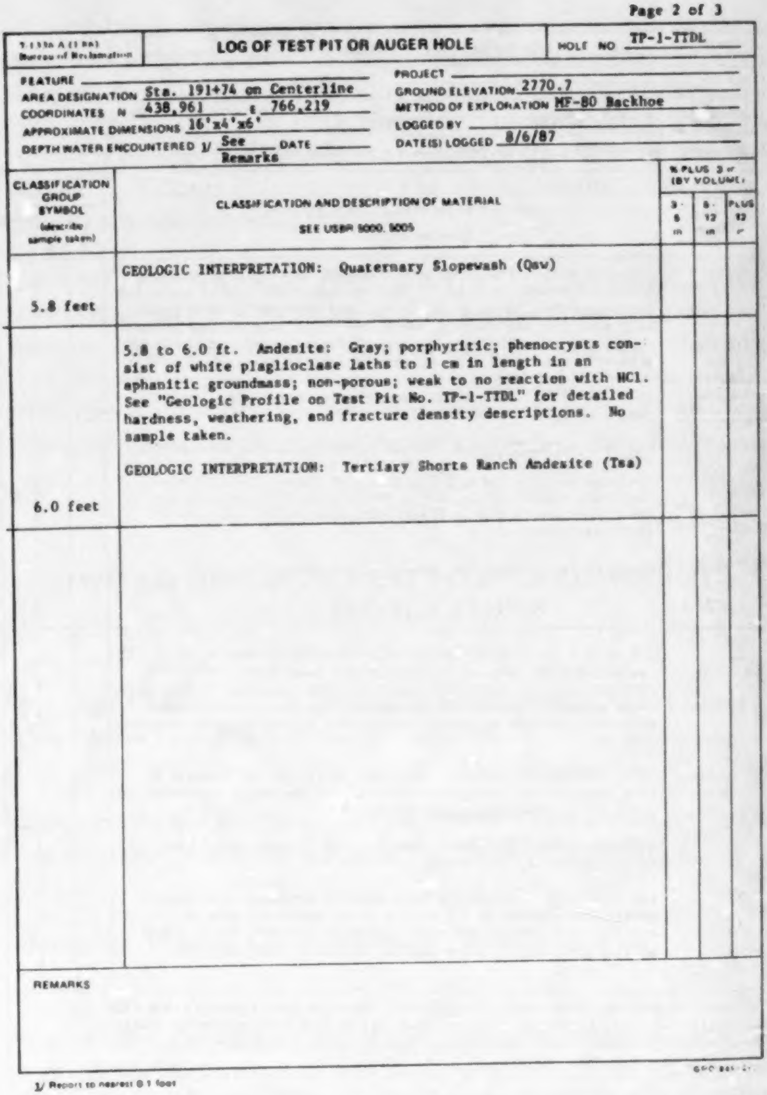
LOGGED BY ________

DATE(S) LOGGED 8/6/87

CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME)		
		3-6 in	6-12 in	PLUS 12 in
(SC)g two 60-lbm sacks 2.0 feet	0.0 to 2.0 ft. CLAYEY SAND WITH GRAVEL AND TRACE OF COBBLES: About 45% coarse to fine, angular to subangular sand; about 40% coarse to fine, angular to subangular, brittle to hard gravel with weak surface coating; about 15% fines with medium to hard plasticity, no dilatancy, medium toughness, medium to high dry strength; max. size, 250 mm; dry, brown; no reaction with HCl. IN-PLACE CONDITION: Dense, homogeneous, root holes, weak cementation, moist to wet. LAB TEST DATA: Two sack samples taken from 2-ft-wide swath at 1.5 ft depth across trench. Material mixed and quartered to get test sample. 35% sand, 51% gravel, 14% fines, LL=53, PI=34. Max. unit weight, opt.: 112.3 lbf/ft^3, 15.6%. Laboratory Classification is Clayey Gravel with Sand (GC)s. (Nondispersive). GEOLOGIC INTERPRETATION: Quaternary Slopewash (Qsw)	T	T	0
(GC)sc two 60-lbm sacks	2.0 to 5.8 ft. CLAYEY GRAVEL WITH SAND AND COBBLES: About 45% coarse to fine, angular to subangular, hard gravel with weak surface coating; about 40% coarse to fine, angular to subangular sand; about 15% fines with medium to high plasticity, slow dilatancy, medium toughness, medium dry strength; weak reaction with HCl. TOTAL SAMPLE (BY VOLUME): About 5% 75 to 125 mm, brittle to hard, angular to subangular cobbles, and boulders; remainder minus 75 mm; max. dimension 550 mm. IN-PLACE CONDITION: Dense, heterogeneous, sand and fines, weakly cemented, dry, brown. LAB TEST DATA: Two 60-lbm sack samples obtained from backhoe bucket from depths of 4.5 to 5.5 ft on northeast side of trench. 43% gravel, 35% sand, 22% fines; LL=50, PI=31. Max. unit weight, opt.: 118.6 lbf/ft^3, 13.3%. (Nondispersive).	5	T	T

REMARKS Moderate ground cover of sagebrush. Maximum size boulder taken from excavation was 550x325x200 mm. Stopped test pit at 6.0 feet unable to excavate further with backhoe. Water encountered only in upper 2.0 ft due to rain from previous three days.

Figure 11-22. Geologic interpretation in test pit (sheet 1).



Page 2 of 3

7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. TP-1-TTDL

FEATURE
AREA DESIGNATION Sta. 191+74 on Centerline
COORDINATES N 438,961 E 766,219
APPROXIMATE DIMENSIONS 16'x4'x6'
DEPTH WATER ENCOUNTERED 1/ See Remarks DATE
PROJECT
GROUND ELEVATION 2770.7
METHOD OF EXPLORATION MF-80 Backhoe
LOGGED BY
DATE(S) LOGGED 8/6/87

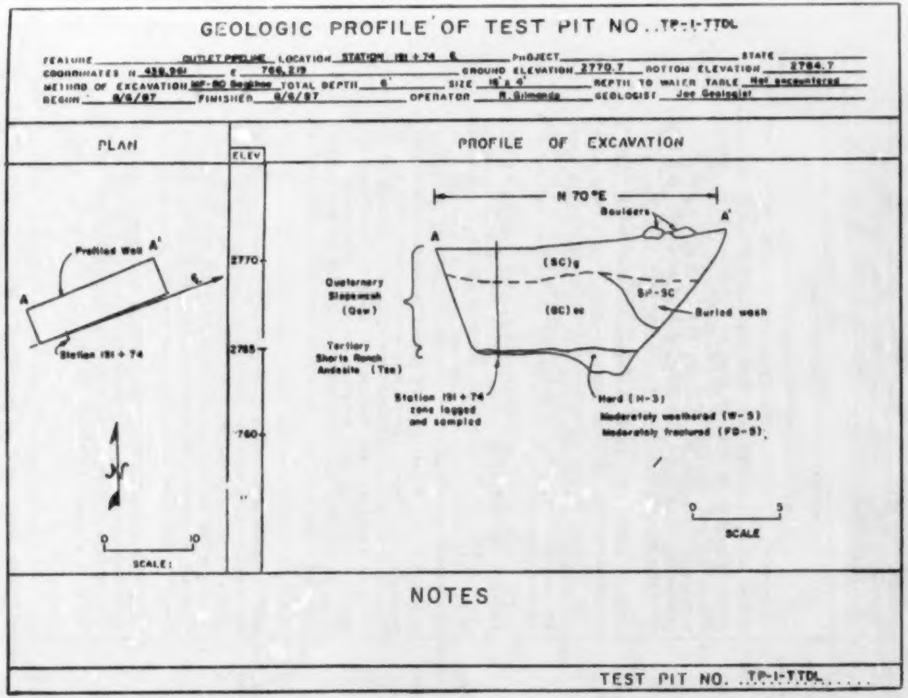
CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME)		
		3-6 in	6-12 in	PLUS 12 in
5.8 feet	GEOLOGIC INTERPRETATION: Quaternary Slopewash (Qsw)			
6.0 feet	5.8 to 6.0 ft. Andesite: Gray; porphyritic; phenocrysts consist of white plagioclase laths to 1 cm in length in an aphanitic groundmass; non-porous; weak to no reaction with HCl. See "Geologic Profile on Test Pit No. TP-1-TTDL" for detailed hardness, weathering, and fracture density descriptions. No sample taken. GEOLOGIC INTERPRETATION: Tertiary Shorts Ranch Andesite (Tsa)			

REMARKS

GPO 841-[illegible]

1/ Report to nearest 0.1 foot

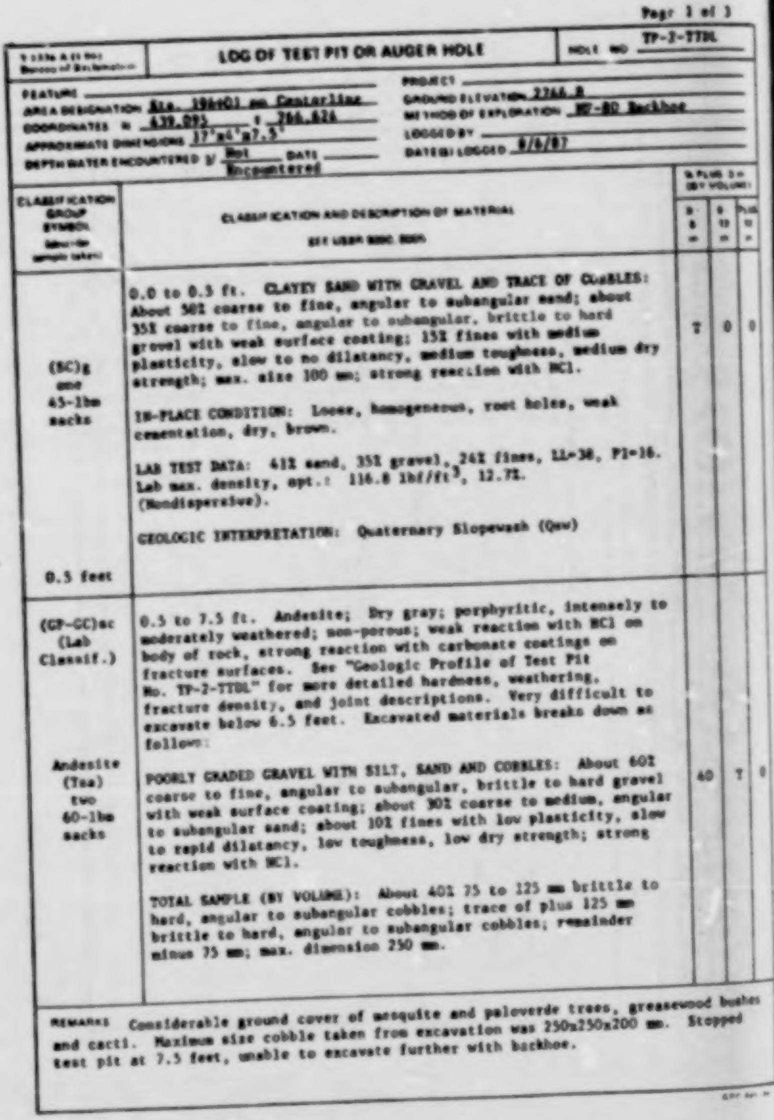
Figure 11-23. Geologic interpretation in test pit (sheet 2).



GEOLOGIC PROFILE OF TEST PIT NO..TP-1-TTDL

FEATURE Outlet Pipeline LOCATION Station 191+74 ℄ PROJECT ____ STATE ____
COORDINATES N 439,961 E 766,219 GROUND ELEVATION 2770.7 BOTTOM ELEVATION 2764.7
METHOD OF EXCAVATION WF-80 Backhoe TOTAL DEPTH 6' SIZE 15' x 4' DEPTH TO WATER TABLE Not encountered
BEGIN 6/6/87 FINISHED 6/6/87 OPERATOR R. Gilmonda GEOLOGIST Joe Geologist

Figure 11-24. Geologic interpretation in test pit (geologic profile).



Page 1 of 3

7-1336 A (3-84)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. TP-2-TTDL

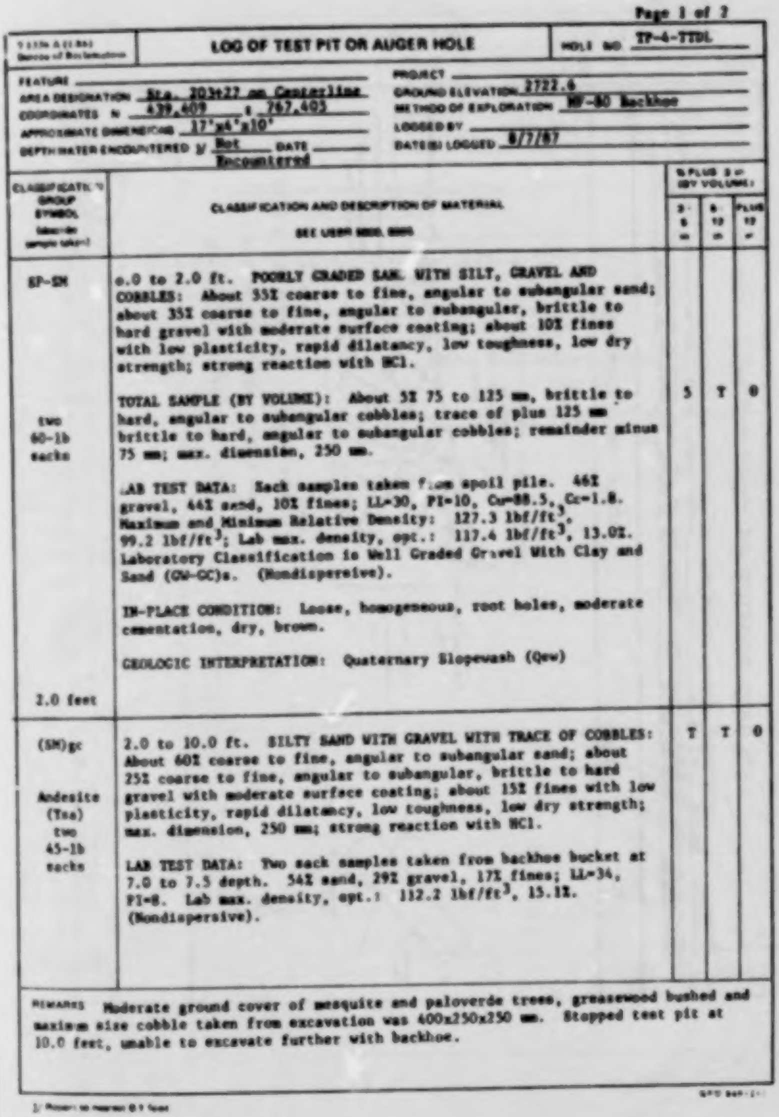
FEATURE
AREA DESIGNATION Sta. 196+01 on Centerline
COORDINATES N 439,095 E 266,626
APPROXIMATE DIMENSIONS 17'x4'x7.5'
DEPTH WATER ENCOUNTERED 1/ Not Encountered DATE

PROJECT
GROUND ELEVATION 2766.8
METHOD OF EXPLORATION MF-80 Backhoe
LOGGED BY
DATE(S) LOGGED 8/6/87

CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL (SEE USBR 5000, 5005)	% PLUS 3 in (BY VOLUME) 3-5 in	5-12 in	Plus 12 in
(SC)g one 45-lbm sacks 0.5 feet	0.0 to 0.5 ft. CLAYEY SAND WITH GRAVEL AND TRACE OF COBBLES: About 50% coarse to fine, angular to subangular sand; about 35% coarse to fine, angular to subangular, brittle to hard gravel with weak surface coating; 15% fines with medium plasticity, slow to no dilatancy, medium toughness, medium dry strength; max. size 100 mm; strong reaction with HCl. IN-PLACE CONDITION: Loose, homogeneous, root holes, weak cementation, dry, brown. LAB TEST DATA: 41% sand, 35% gravel, 24% fines, LL=30, PI=16. Lab max. density, opt.: 116.8 lbf/ft³, 12.7%. (Nondispersive). GEOLOGIC INTERPRETATION: Quaternary Slopewash (Qsw)	T	0	0
(GP-GC)sc (Lab Classif.) Andesite (Tsa) two 60-lbm sacks	0.5 to 7.5 ft. Andesite; Dry gray; porphyritic, intensely to moderately weathered; non-porous; weak reaction with HCl on body of rock, strong reaction with carbonate coatings on fracture surfaces. See "Geologic Profile of Test Pit No. TP-2-TTDL" for more detailed hardness, weathering, fracture density, and joint descriptions. Very difficult to excavate below 6.5 feet. Excavated materials breaks down as follows: POORLY GRADED GRAVEL WITH SILT, SAND AND COBBLES: About 60% coarse to fine, angular to subangular, brittle to hard gravel with weak surface coating; about 30% coarse to medium, angular to subangular sand; about 10% fines with low plasticity, slow to rapid dilatancy, low toughness, low dry strength; strong reaction with HCl. TOTAL SAMPLE (BY VOLUME): About 40% 75 to 125 mm brittle to hard, angular to subangular cobbles; trace of plus 125 mm brittle to hard, angular to subangular cobbles; remainder minus 75 mm; max. dimension 250 mm.	40	T	0

REMARKS Considerable ground cover of mesquite and paloverde trees, greasewood bushes and cacti. Maximum size cobble taken from excavation was 250x250x200 mm. Stopped test pit at 7.5 feet, unable to excavate further with backhoe.

Figure 11-25. Geologic interpretation in test pit (sheet 3).



Page 1 of 2

Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. TP-4-TTDL

FEATURE
AREA DESIGNATION Sta. 203+27 on Centerline
COORDINATES N 639,609 E 767,403
APPROXIMATE DIMENSIONS 17'x4'x10'
DEPTH WATER ENCOUNTERED 1/ Not Encountered DATE

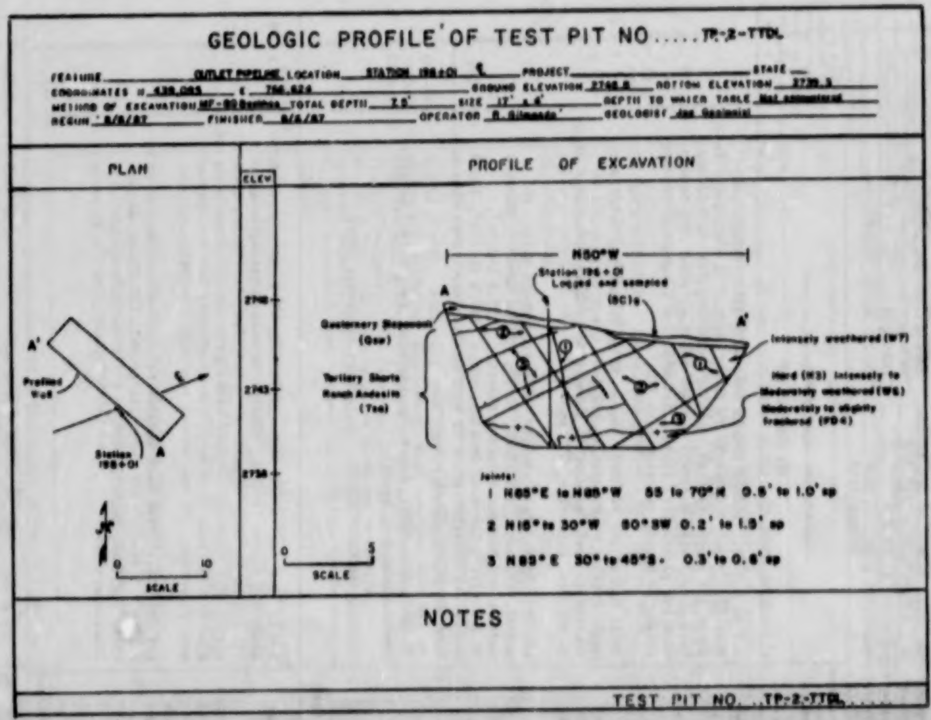
PROJECT
GROUND ELEVATION 2722.6
METHOD OF EXPLORATION MF-80 Backhoe
LOGGED BY
DATE(S) LOGGED 8/7/87

CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME) 3-6 in	6-12 in	PLUS 12 in
SP-SM two 60-lb sacks 2.0 feet	0.0 to 2.0 ft. POORLY GRADED SAND WITH SILT, GRAVEL AND COBBLES: About 55% coarse to fine, angular to subangular sand; about 35% coarse to fine, angular to subangular, brittle to hard gravel with moderate surface coating; about 10% fines with low plasticity, rapid dilatancy, low toughness, low dry strength; strong reaction with HCl. TOTAL SAMPLE (BY VOLUME): About 5% 75 to 125 mm, brittle to hard, angular to subangular cobbles; trace of plus 125 mm brittle to hard, angular to subangular cobbles; remainder minus 75 mm; max. dimension, 250 mm. LAB TEST DATA: Sack samples taken from spoil pile. 46% gravel, 44% sand, 10% fines; LL=30, PI=10, Cu=88.5, Cc=1.8. Maximum and Minimum Relative Density: 127.3 lbf/ft^3, 99.2 lbf/ft^3; Lab max. density, opt.: 117.4 lbf/ft^3, 13.0%. Laboratory Classification is Well Graded Gravel With Clay and Sand (GW-GC)s. (Nondispersive). IN-PLACE CONDITION: Loose, homogeneous, root holes, moderate cementation, dry, brown. GEOLOGIC INTERPRETATION: Quaternary Slopewash (Qsw)	5	T	0
(SM)gc Andesite (Tsa) two 45-lb sacks	2.0 to 10.0 ft. SILTY SAND WITH GRAVEL WITH TRACE OF COBBLES: About 60% coarse to fine, angular to subangular sand; about 25% coarse to fine, angular to subangular, brittle to hard gravel with moderate surface coating; about 15% fines with low plasticity, rapid dilatancy, low toughness, low dry strength; max. dimension, 250 mm; strong reaction with HCl. LAB TEST DATA: Two sack samples taken from backhoe bucket at 7.0 to 7.5 depth. 54% sand, 29% gravel, 17% fines; LL=34, PI=8. Lab max. density, opt.: 112.2 lbf/ft^3, 15.1%. (Nondispersive).	T	T	0

REMARKS Moderate ground cover of mesquite and paloverde trees, greasewood bushed and maximum size cobble taken from excavation was 400x250x250 mm. Stopped test pit at 10.0 feet, unable to excavate further with backhoe.

1/ Report to nearest 0.1 foot

Figure 11-26. Geologic interpretation in test pit (sheet 4).



GEOLOGIC PROFILE OF TEST PIT NO.....TP-2-TTDL

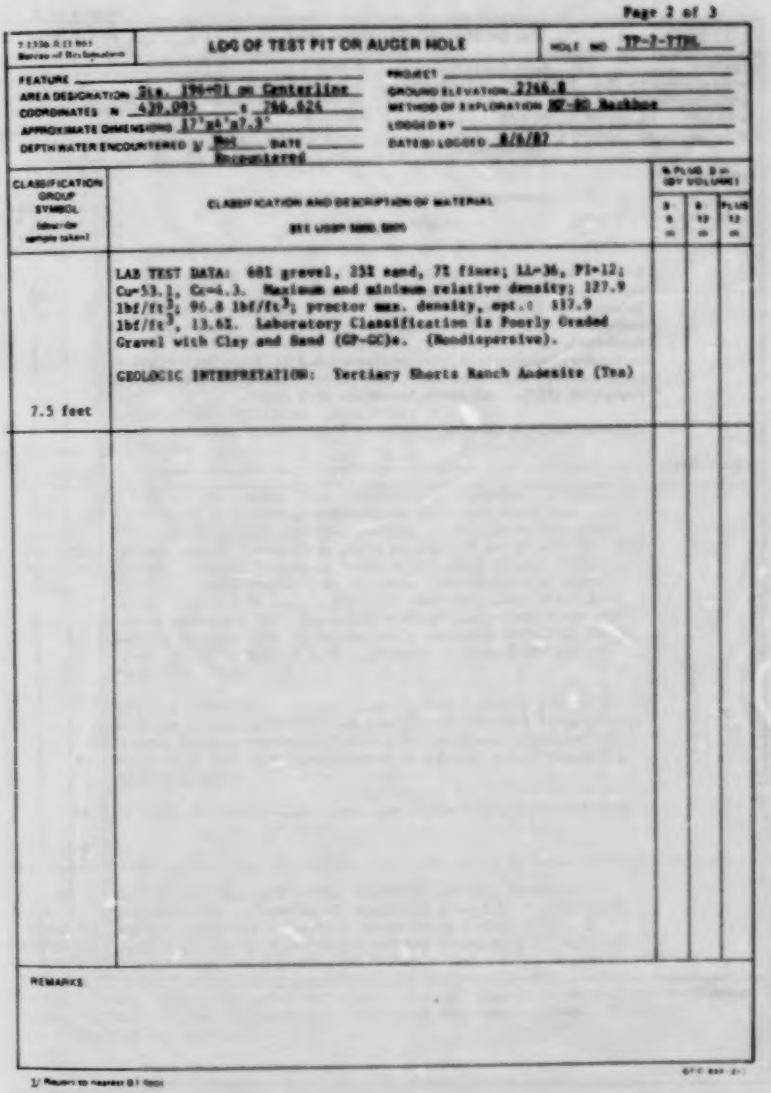
FEATURE OUTLET PIPELINE LOCATION STATION 196+01 ℄ PROJECT ______ STATE __
COORDINATES N 439,085 E 756,624 GROUND ELEVATION 2746.8 BOTTOM ELEVATION 2739.3
METHOD OF EXCAVATION [illegible] TOTAL DEPTH 7.5' SIZE 17' x 4' DEPTH TO WATER TABLE Not encountered
BEGUN 8/6/87 FINISHED 8/6/87 OPERATOR [illegible] GEOLOGIST [illegible]

Joints:
1 N65°E to N65°W 55 to 70°N 0.5' to 1.0' sp
2 N15° to 30°W 80°SW 0.2' to 1.5' sp
3 N85°E 30° to 45°S. 0.3' to 0.6' sp

NOTES

TEST PIT NO. TP-2-TTDL

Figure 11-27. Geologic interpretation in test pit (geologic profile 2).



Page 2 of 3

7-1336 (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. TP-2-TTDL

FEATURE
AREA DESIGNATION Sta. 196+01 on Centerline
COORDINATES N 439,093 E 766,624
APPROXIMATE DIMENSIONS 17'x4'x7.3'
DEPTH WATER ENCOUNTERED 1/ Not Encountered DATE

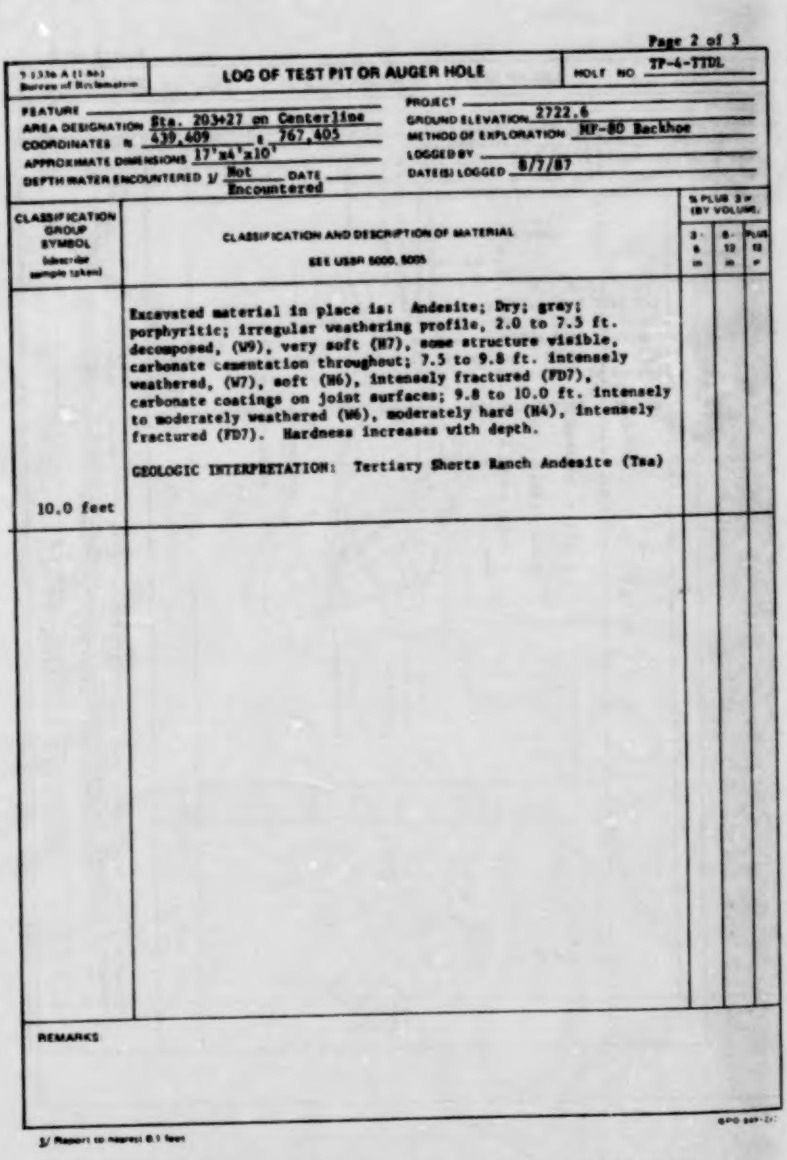
PROJECT
GROUND ELEVATION 2266.8
METHOD OF EXPLORATION JD-80 Backhoe
LOGGED BY
DATE(S) LOGGED 8/6/87

CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL (SEE USBR 5000, 5005)	% PLUS 3 in (BY VOLUME) 3-5 in	5-12 in	PLUS 12 in
7.5 feet	LAB TEST DATA: 60% gravel, 23% sand, 7% fines; LL=36, PI=12; Cu=53.1, Cc=4.3. Maximum and minimum relative density; 127.9 lbf/ft^3; 96.8 lbf/ft^3; proctor max. density, opt.: 117.9 lbf/ft^3, 13.6%. Laboratory Classification is Poorly Graded Gravel with Clay and Sand (GP-GC)s. (Nondispersive). GEOLOGIC INTERPRETATION: Tertiary Shorts Ranch Andesite (Tsa)			

REMARKS

1/ Report to nearest 0.1 foot

Figure 11-28. Geologic interpretation in test pit (sheet 5).



Page 2 of 3

7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. TP-4-TTDL

FEATURE
AREA DESIGNATION Sta. 203+27 on Centerline
COORDINATES N 439,409 E 767,405
APPROXIMATE DIMENSIONS 17'x4'x10'
DEPTH WATER ENCOUNTERED 1/ Not Encountered DATE

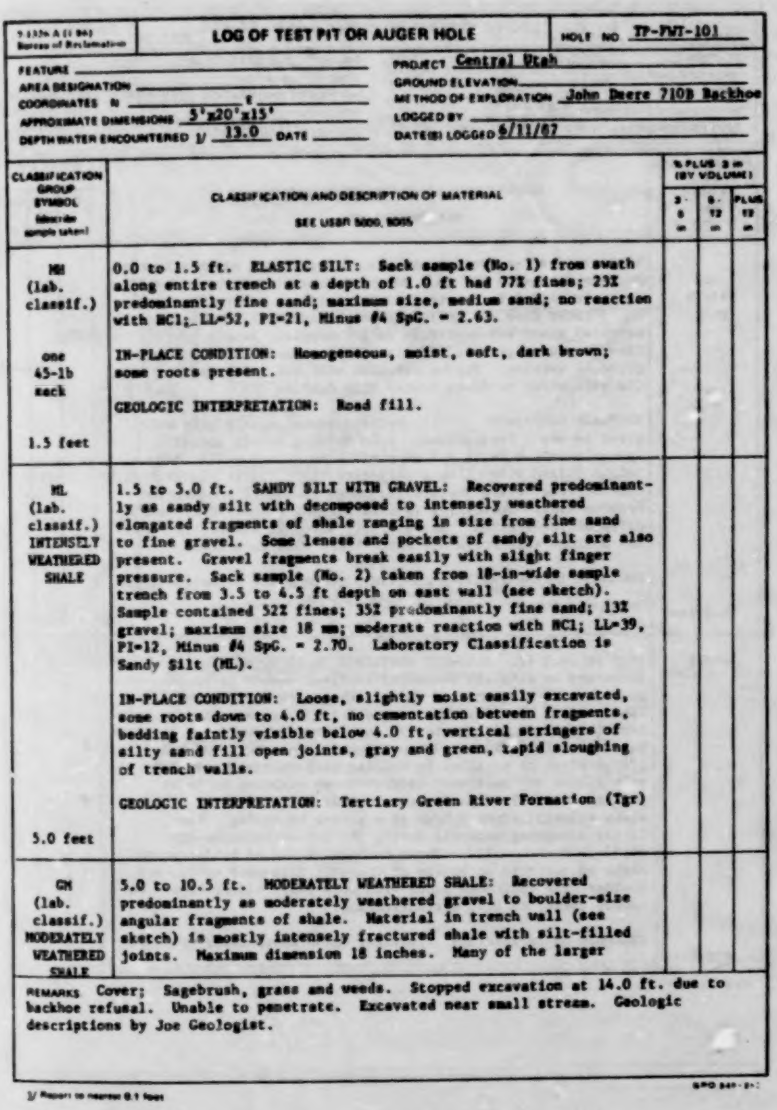
PROJECT
GROUND ELEVATION 2722.6
METHOD OF EXPLORATION MF-80 Backhoe
LOGGED BY
DATE(S) LOGGED 8/7/87

CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME) 3-6 in	6-12 in	PLUS 12 in
10.0 feet	Excavated material in place is: Andesite; Dry; gray; porphyritic; irregular weathering profile, 2.0 to 7.5 ft. decomposed, (W9), very soft (H7), some structure visible, carbonate cementation throughout; 7.5 to 9.8 ft. intensely weathered, (W7), soft (H6), intensely fractured (FD7), carbonate coatings on joint surfaces; 9.8 to 10.0 ft. intensely to moderately weathered (W6), moderately hard (H4), intensely fractured (FD7). Hardness increases with depth. GEOLOGIC INTERPRETATION: Tertiary Sherts Ranch Andesite (Tsa)			

REMARKS

1/ Report to nearest 0.1 feet

Figure 11-29. Geologic interpretation in test pit (sheet 6).



7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. TP-FVT-101

FEATURE ______
AREA DESIGNATION ______
COORDINATES N ______ E ______
APPROXIMATE DIMENSIONS 5'x20'x15'
DEPTH WATER ENCOUNTERED 1/ 13.0 DATE ______
PROJECT Central Utah
GROUND ELEVATION ______
METHOD OF EXPLORATION John Deere 710B Backhoe
LOGGED BY ______
DATE(S) LOGGED 6/11/87

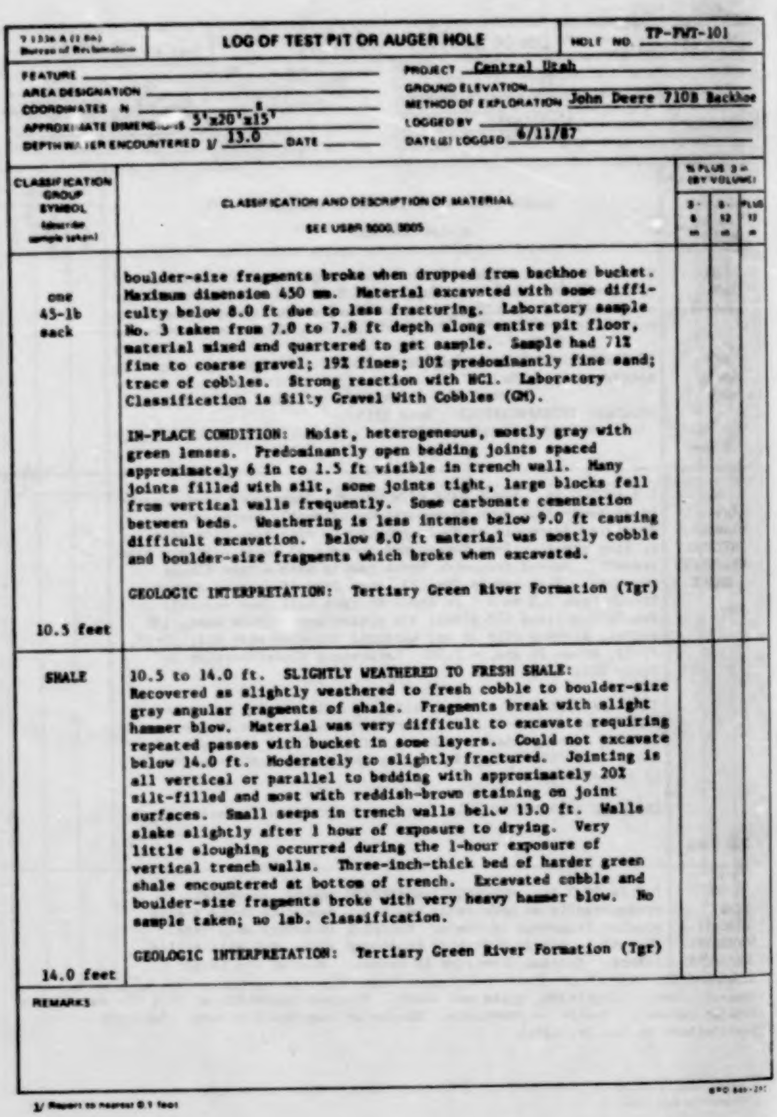
CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME) 3-5 in	5-12 in	PLUS 12 in
MH (lab. classif.) one 45-lb sack 1.5 feet	0.0 to 1.5 ft. ELASTIC SILT: Sack sample (No. 1) from swath along entire trench at a depth of 1.0 ft had 77% fines; 23% predominantly fine sand; maximum size, medium sand; no reaction with HCl; LL=52, PI=21, Minus #4 SpG. = 2.63. IN-PLACE CONDITION: Homogeneous, moist, soft, dark brown; some roots present. GEOLOGIC INTERPRETATION: Road fill.			
ML (lab. classif.) INTENSELY WEATHERED SHALE 5.0 feet	1.5 to 5.0 ft. SANDY SILT WITH GRAVEL: Recovered predominantly as sandy silt with decomposed to intensely weathered elongated fragments of shale ranging in size from fine sand to fine gravel. Some lenses and pockets of sandy silt are also present. Gravel fragments break easily with slight finger pressure. Sack sample (No. 2) taken from 18-in-wide sample trench from 3.5 to 4.5 ft depth on east wall (see sketch). Sample contained 52% fines; 35% predominantly fine sand; 13% gravel; maximum size 18 mm; moderate reaction with HCl; LL=39, PI=12, Minus #4 SpG. = 2.70. Laboratory Classification is Sandy Silt (ML). IN-PLACE CONDITION: Loose, slightly moist easily excavated, some roots down to 4.0 ft, no cementation between fragments, bedding faintly visible below 4.0 ft, vertical stringers of silty sand fill open joints, gray and green, rapid sloughing of trench walls. GEOLOGIC INTERPRETATION: Tertiary Green River Formation (Tgr)			
GM (lab. classif.) MODERATELY WEATHERED SHALE	5.0 to 10.5 ft. MODERATELY WEATHERED SHALE: Recovered predominantly as moderately weathered gravel to boulder-size angular fragments of shale. Material in trench wall (see sketch) is mostly intensely fractured shale with silt-filled joints. Maximum dimension 18 inches. Many of the larger			

REMARKS Cover; Sagebrush, grass and weeds. Stopped excavation at 14.0 ft. due to backhoe refusal. Unable to penetrate. Excavated near small stream. Geologic descriptions by Joe Geologist.

1/ Report to nearest 0.1 foot

GPO 849-[illegible]

Figure 11-30. Geologic interpretation in test pit (sheet 7).



7-1336-A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. TP-FWT-101

FEATURE
AREA DESIGNATION
COORDINATES N E
APPROXIMATE DIMENSIONS 5'x20'x15'
DEPTH WATER ENCOUNTERED 1/ 13.0 DATE
PROJECT Central Utah
GROUND ELEVATION
METHOD OF EXPLORATION John Deere 710B Backhoe
LOGGED BY
DATE(S) LOGGED 6/11/87

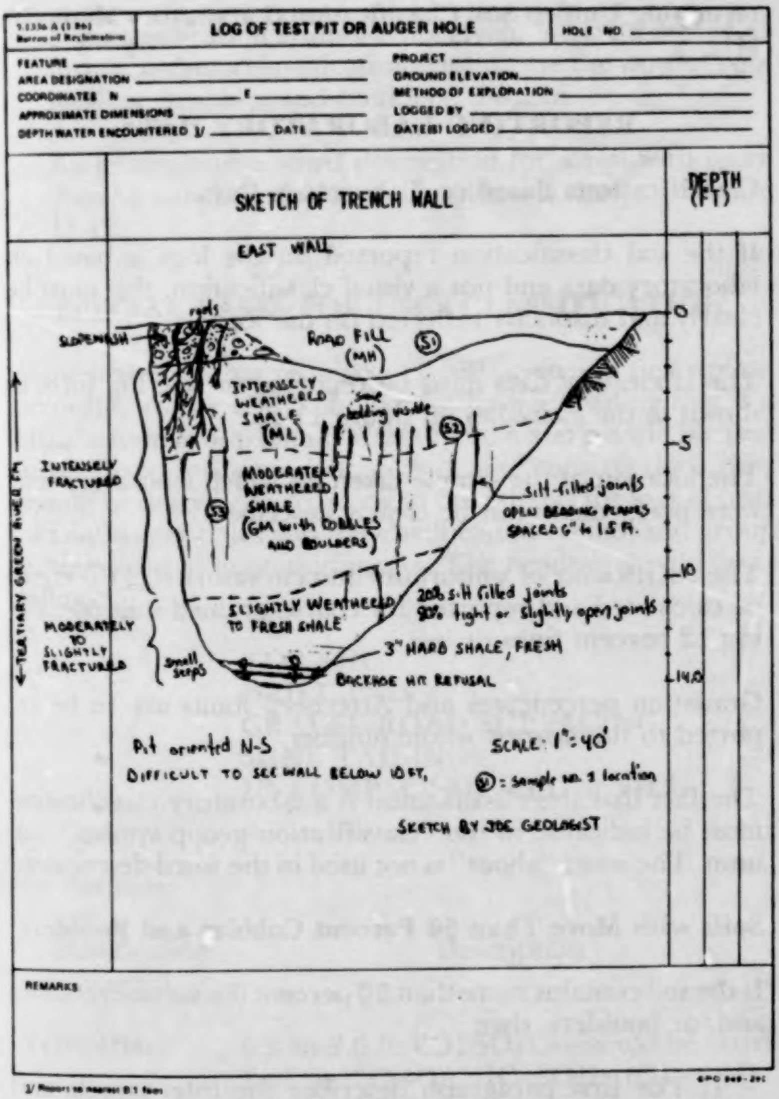
CLASSIFICATION GROUP SYMBOL (describe sample taken)	CLASSIFICATION AND DESCRIPTION OF MATERIAL SEE USBR 5000, 5005	% PLUS 3 in (BY VOLUME) 3-6 in	6-12 in	PLUS 12 in
one 45-lb sack 10.5 feet	boulder-size fragments broke when dropped from backhoe bucket. Maximum dimension 450 mm. Material excavated with some difficulty below 8.0 ft due to less fracturing. Laboratory sample No. 3 taken from 7.0 to 7.8 ft depth along entire pit floor, material mixed and quartered to get sample. Sample had 71% fine to coarse gravel; 19% fines; 10% predominantly fine sand; trace of cobbles. Strong reaction with HCl. Laboratory Classification is Silty Gravel With Cobbles (GM). IN-PLACE CONDITION: Moist, heterogeneous, mostly gray with green lenses. Predominantly open bedding joints spaced approximately 6 in to 1.5 ft visible in trench wall. Many joints filled with silt, some joints tight, large blocks fell from vertical walls frequently. Some carbonate cementation between beds. Weathering is less intense below 9.0 ft causing difficult excavation. Below 8.0 ft material was mostly cobble and boulder-size fragments which broke when excavated. GEOLOGIC INTERPRETATION: Tertiary Green River Formation (Tgr)			
SHALE 14.0 feet	10.5 to 14.0 ft. SLIGHTLY WEATHERED TO FRESH SHALE: Recovered as slightly weathered to fresh cobble to boulder-size gray angular fragments of shale. Fragments break with slight hammer blow. Material was very difficult to excavate requiring repeated passes with bucket in some layers. Could not excavate below 14.0 ft. Moderately to slightly fractured. Jointing is all vertical or parallel to bedding with approximately 20% silt-filled and most with reddish-brown staining on joint surfaces. Small seeps in trench walls below 13.0 ft. Walls slake slightly after 1 hour of exposure to drying. Very little sloughing occurred during the 1-hour exposure of vertical trench walls. Three-inch-thick bed of harder green shale encountered at bottom of trench. Excavated cobble and boulder-size fragments broke with very heavy hammer blow. No sample taken; no lab. classification. GEOLOGIC INTERPRETATION: Tertiary Green River Formation (Tgr)			

REMARKS

GPO [illegible]

1/ Report to nearest 0.1 foot

Figure 11-31. Geologic interpretation in test pit (sheet 8).



7-1336 A (1-86)
Bureau of Reclamation

LOG OF TEST PIT OR AUGER HOLE

HOLE NO. ______

FEATURE ______
AREA DESIGNATION ______
COORDINATES N ______ E ______
APPROXIMATE DIMENSIONS ______
DEPTH WATER ENCOUNTERED 1/ ______ DATE ______

PROJECT ______
GROUND ELEVATION ______
METHOD OF EXPLORATION ______
LOGGED BY ______
DATE(S) LOGGED ______

SKETCH OF TRENCH WALL

DEPTH (FT)

EAST WALL

roots
SLOPEWASH
ROAD FILL (MH)
(S1)
INTENSELY WEATHERED SHALE (ML)
some bedding visible
(S2)
MODERATELY WEATHERED SHALE (GM with COBBLES AND BOULDERS)
(S3)
silt-filled joints
OPEN BEDDING PLANES SPACED 6" to 1.5 ft.
20% silt filled joints
80% tight or slightly open joints
SLIGHTLY WEATHERED TO FRESH SHALE
3" HARD SHALE, FRESH
BACKHOE HIT REFUSAL
small seeps
INTENSELY FRACTURED
MODERATELY TO SLIGHTLY FRACTURED
← TERTIARY GREEN RIVER FM →
0
5
10
14.0

Pit oriented N-S

DIFFICULT TO SEE WALL BELOW 10 FT.

SCALE: 1" = 40'

(S1) = sample no. 1 location

SKETCH BY JOE GEOLOGIST

REMARKS

1/ Report to nearest 0.1 feet

GPO 849-291

Figure 11-32. Geologic interpretation in test pit (geologic profile 3).

This example uses the abbreviated method of indicating the group name with the group symbol. This abbreviated method is described in appendix X5 in USBR 5000, "Determining Unified Soil Classification (Laboratory Method)" [1].

REPORTING LABORATORY DATA

Classifications Based on Laboratory Data

If the soil classification reported on the logs is based on laboratory data and not a visual classification, this must be clearly and distinctly reflected on the log.

The laboratory data must be reported on the log form as shown in the examples on figure 11-11.

The location of the sample taken on which laboratory tests were performed must be clearly described.

The coefficients of uniformity and curvature (C_u, C_c) are to be calculated and reported for coarse-grained soils containing 12 percent fines or less.

Gradation percentages and Atterberg limits are to be reported to the nearest whole number.

The fact that the classification is a laboratory classification must be indicated in the "classification group symbol" column. The word "about" is not used in the word description.

Soils with More Than 50 Percent Cobbles and Boulders

If the soil contains more than 50 percent (by volume) cobbles and/or boulders, then:

1. The first paragraph describes the total sample and includes the information on the cobbles and boulders. The information in the paragraph is the same as described previously for cobbles and/or boulders.

2. The words "COBBLES" or "COBBLES AND BOULDERS" are listed first in the classification group name:

COBBLES WITH POORLY GRADED GRAVEL
COBBLES AND BOULDERS WITH SILTY GRAVEL

3. A classification symbol is *not* given. Where a report or form requires a classification symbol, use the words "cobbles" or "cobbles and boulders" instead.

An example of a word description for a soil with more than 50 percent cobbles and boulders is shown on figure 11-12.

SPECIAL CASES FOR USCS CLASSIFICATION

Some materials that require a classification and description according to the USCS should not have a heading that is a classification group name. When these materials will be used in, or have influence on, design and construction, they should be described according to the criteria for logs of tests pits and auger holes and the classification symbol and group name placed in quotation marks. The heading should be as follows:

TOPSOIL
DRILL PAD
GRAVEL ROAD SURFACING
MINE TAILINGS
UNCOMPACTED FILL or FILL

for example:

Classification symbol	Description
TOPSOIL	0.0 to 2.6 ft TOPSOIL—would be classified as "ORGANIC SOIL (OL/OH)." About 90% fines with low plasticity, slow dilatancy, low dry strength, and low toughness; about 10% fine to medium sand; soft, wet, dark brown, organic odor; roots present throughout strata; weak reaction with HCl.

REPORTING IN-PLACE UNIT WEIGHT TESTS

In-place unit weight tests are sometimes performed in test pits in borrow areas for compacted embankments so that the in-place unit weights can be compared with the expected compacted unit weight for the embankment and the required volume of material needed from the borrow area can be calculated. The in-place unit weight also is used to evaluate the expansive potential or the "collapse" potential for certain soils. For pipeline investigations, the percent compaction (or percent relative density) is determined to evaluate the competency of trench walls for the pipe. See Training Manual No. 7, "Pipe Bedding and Backfill" [5].

The in-place unit weight should be reported in the paragraph on in-place condition. Examples of the format are shown on figure 11-10. The upper example is used when only the in-place unit weight is determined and the lower example when a laboratory compaction test is also performed to calculate the percent compaction (or D value if rapid method is used) [6].

For cohesionless soils, similar information is reported for the maximum index unit weight, the minimum index unit weight, and the percent relative density.

If the in-place unit weight test hole spans two (or more) depth intervals of classification, the data and comments for the test should be placed in the interval description corresponding to the top of the test hole. At the end of the information reported, the comment (in all capital letters) must be added: "NOTE: TEST EXTENDED INTO UNDERLYING INTERVAL."

Since the laboratory compaction test is generally performed on the material removed from the test hole, it must be noted that the data are for a mixture of intervals. Add a note, "NOTE: COMPACTION TEST PERFORMED ON MATERIAL MIXED FROM TWO DIFFERENT INTERVALS."

The unit weight is to be stated in terms of lbf/ft^3 (pounds-force per cubic foot) or kN/m^3 (kilonewtons per cubic meter). See Training Manual No. 1 [7] for the explanation of terms.

Samples Taken

In addition to the brief description of the samples taken under the "Classification Group Symbol" column, a more complete description of any samples taken from each depth interval is included in the word description. The description should include the size of the sample, the location represented by the sample, and for each sample how the sample was obtained (e.g., quartering and splitting).

An example of how to report the sample information for an auger hole is shown on figure 11-16. An example of how to report the sample information for a test pit or trench is shown in the section on word descriptions of undisturbed samples.

The approximate mass of sack samples should be stated in terms of lbm (pounds-mass) or kg (kilograms). For an explanation of why mass and lbm are used, see Geotechnical Branch Training Manual No. 1, "Moisture-Unit Weight Relationship of Soils" [7].

Measured Percentages of Cobbles and Boulders

If the percentages of the plus 3-inch particles are measured, not estimated, the percentages are reported to the nearest 1 percent. In the word description for the plus 3-inch particles, do not use the term "about" before the percentages.

The procedure for measuring the percent by volume of cobbles and boulders is given in the test procedure, USBR 7000, "Performing Disturbed Soil Sampling in Test Pits" [8].

It is not recommended that the percentages be measured for auger holes since the mass of material recovered is generally insufficient to obtain a reliable gradation of plus 3-inch particles.

Figures 11-22 through 11-32 show a variety of logs of test pits using both the Unified Soil Classification System (USCS) and the geologic interpretation of the parent material. Note that USCS indicates that bedrock has been altered or weathered or soil-like conditions. For engineering considerations use the USCS but present the rock conditions as well.

BIBLIOGRAPHY

[1] Bureau of Reclamation, Geotechnical Branch Training Manual No. 4, Denver, Office, Denver CO.

[2] Bureau of Reclamation, Geotechnical Branch Training Manual No. 5, Denver Office, Denver CO.

[3] U.S. Department of Agriculture, Agriculture Handbook No. 436, Appendix I (Soil Taxonomy), December 1975.

[4] Bureau of Reclamation, *Earth Manual*, 2nd edition, Denver, Office, Denver CO, 1974 (reprinted 1980).

[5] Bureau of Reclamation, Geotechnical Branch Training Manual No. 7, Denver Office, Denver CO.

[6] Bureau of Reclamation, Geotechnical Branch Training Manual No. 3, Denver Office, Denver CO, 1982

[7] Bureau of Reclamation, Geotechnical Branch Training Manual No. 1, Denver Office, Denver CO, December 1979.

[8] Bureau of Reclamation, "Performing Disturbed Soil Sampling in Test Pits, Trenches, Accessible Borings and Tunnels," Denver Office, Denver CO, in preparation.

Chapter 12
INTRODUCTION TO PART II

This part provides references, charts, and tables useful to the geologist especially during the course of investigation. The part is divided into two sections. The first section contains references, and the second section contains useful charts, tables and formulas.

The references provide useful "need to know" information on subjects related to geology but to which some of the geologists may not be familiar. Subjects range from an introduction to geophysical methods through such topics as data collection for design and construction blasting. Other subjects including landslides and slope stability, quarrying construction materials especially riprap, and dewatering are incidental to geologic investigations and data gathering. Standards for care and retention of core are included in this volume.

The second section is a potpourri of useful data in tabular form. If the reader has any data or tables used regularly and deemed useful to other geologists, please contact the Geology Branch, Denver Office. As the tables and charts are obtained, they will be distributed to the users for use and comment. In addition, these tables will form the basis for a data book type publication for field use.

Special attention is directed to Appendix E. This appendix contains guidelines for geologists involved in instrumentation functions. In addition, the Division of Dam Safety has published *Embankment Dam Instrumentation Manual*, January 1987. Much of the material included in Appendix E has been derived from this instrumentation manual.

Critical comments on the chapters or appendices, including suggestions for improvement, are solicited from Reclamation geologists. The ultimate goal for the manual is USBR acceptance and use.

Chapter 13
GEOPHYSICAL INVESTIGATIONS, SERVICES AND EQUIPMENT CAPABILITIES

Geophysical surveys have been applied for mineral (including petroleum) exploration for a number of years. A magnetic compass was used in Sweden in the mid-1600's to explore for iron ore deposits. The lateral extent of the Comstock orebody was mapped using self-potential methods in the 1880's. A very crude type of seismic survey was performed to measure the energy resulting from blasting operations in Ireland in the late 1800's. From this survey, an idea resulted that energy travels through a material with a certain velocity. During World War I, geophysical techniques were used to determine the locations of artillery pieces, and special military detection groups were formed for this purpose. Submarine warfare in World War II led to the advent of magnetic and sonar surveys.

The main emphasis of geophysical surveys in the formative years was for petroleum exploration. From these surveys, technology continually developed, and is developing, that allows geophysical surveys to play important roles in our modern societies. Certainly the emphasis, and dollar volume of geophysical work is dedicated to oil exploration; however, mining exploration also has enjoyed the benefits of this technology. From the late 1950's until the present time, geophysical techniques have had an increasing role in both ground-water exploration projects and in geotechnical projects.

Geophysical surveys have been applied to civil engineering investigations since the late 1920's, when seismic and electrical resistivity surveys were used for dam siting studies. A seismic survey was performed in the 1950's in St. Peter's Basilica to locate buried catacombs prior to a renovation project. With the advent of the nuclear power industry and the requirement for Preliminary Safety Analysis Reports (PSARs) for the site on which each reactor was to be placed, a detailed siting investigation was required. Part of these investigations were performed using geophysical methods. These geophysical surveys attracted the attention of the civil engineering community and the Nuclear Regulatory Commission, so that geophysical surveys are now required by law for these types of investigations. A direct outgrowth of this concept has been a wider acceptance of geophysical surveys by the civil engineering community. Geophysical surveys are now used in an almost routine manner to complement geological investigations and to provide information on site parameters (i.e., in situ dynamic properties, cathodic protection values, depth to bedrock), that in some instances are not obtainable by other methods. Where some site parameters are obtainable by other means, for instance, laboratory testing, the values derived from geophysical surveys are useful, for they are obtained at different strain levels. Figure 13–1 presents an idea of the importance of different geophysical methods used in civil engineering studies.

All geophysical techniques are based on the detection of contrasts in different physical properties of materials. In the event that such contrasts do not exist, geophysical methods will not function. These contrasts range from those of acoustical velocities of materials to contrasts in the electrical properties of materials. The seismic methods, both reflection and refraction, are dependent on the contrast in compressional and/or shear wave velocities of different materials. Electrical methods are dependent on the contrasts in the electrical resistivities. Contrasts in the densities of different materials permit gravity surveys to be used in certain types of investigations. Contrast in magnetic susceptibilities of materials permit magnetic surveying to be used in other investigations. Contrast in the magnitude of the naturally existing electric current within the earth can be detected by self-potential (SP) surveys.

Based on detection and measurement of these contrasts, geophysical surveys can be designed to assist the geologist and civil engineer involved in geotechnical investigations. Seismic refraction surveys are used to map the depth to bedrock, and to provide information on the compressional and shear wave velocities of the various units overlying bedrock. Velocity information also can be used to calculate in situ small strain dynamic properties of these units. Electrical

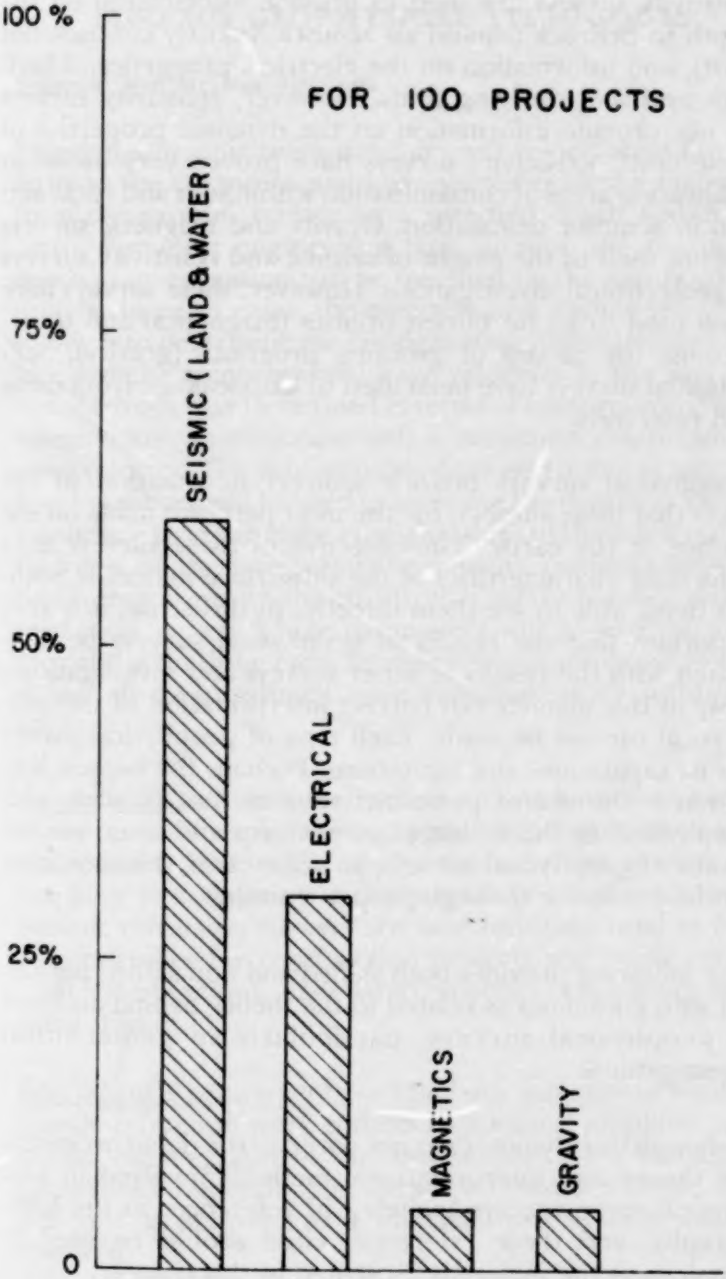


Figure 13-1. – Relative importance of geophysical methods in civil engineering.

resistivity surveys are used to provide information on the depth to bedrock (should an acoustic velocity contrast not exist), and information on the electrical properties of bedrock and the overlying units. However, resistivity surveys do not provide information on the dynamic properties of these units. Resistivity surveys have proven very useful in delineating areas of contamination within soils and rock, and also in acquifer delineation. Gravity and magnetic surveys are not used to the extent of seismic and resistivity surveys in geotechnical investigations. However, these surveys have been used to locate buried utilities (magnetics) and to determine the success of grouting programs (gravity). Self-potential surveys have been used to map leakage from dams and reservoirs.

Geophysical surveys provide indirect information in the sense that these surveys, for the most part, are made on the surface of the earth. The objective of these surveys is to determine characteristics of the subsurface materials, without being able to see them directly. In this sense, it is very important that the results of geophysical surveys be integrated with the results of other surveys and investigations. Only in this manner can correct interpretation of the geophysical surveys be made. Each type of geophysical survey has its capabilities and limitations. Perhaps the biggest limitation is the use of personnel who are not familiar with geophysical methods that plan, perform and interpret the results of geophysical surveys. In some cases, this limitation can be overcome through proper training.

The following provides both skilled and non-skilled personnel with guidelines as related to the theory behind and uses of geophysical surveys, particularly in geotechnical investigations.

Although this chapter does not cover all the detail necessary, the theory and interpretational methods involved in geophysical surveying are included in references in the bibliography, and those references cited should be used to supplement the materials presented in this chapter.

SURFACE GEOPHYSICAL TECHNIQUES

Seismic Refraction Surveys

Purpose.—Seismic refraction surveys are performed to determine the compressional wave velocities of the materials from the ground surface to a specified depth within the earth. For most engineering type surveys, the maximum depth of investigation will be specified by the nature of the project. In many cases, the objective of a seismic refraction survey is to determine the configuration of the bedrock surface and the compressional wave velocities in the overburden. Bedrock may be defined in terms of compressional wave velocity, i.e., as materials with a minimum compressional wave velocity. The information obtained from a seismic refraction survey will be used to compute the depths to various subsurface layers, and the configurations of these layers. The thickness of the layers and the velocity contrasts between the layers will govern the effectiveness of the planned seismic refraction survey. These parameters will govern the accuracy of the resulting data. Seismic refraction surveys will not define all compressional wave velocities or all subsurface layers.

Applications.—Seismic refraction surveys have been used in many types of exploration programs and geotechnical investigations. The initial application of these surveys was mapping of salt domes in the early days of oil exploration. Seismic refraction surveys are now routinely used in foundation studies for construction projects and siting studies, fault investigations, dam safety analyses and tunnel alignment studies.

Equipment Requirements.—The basic equipment used for seismic refraction work consists of a seismic amplifier, a recorder (oscillograph or an oscilliscope) and a transducer (geophone). Depending on the scope of work, a single channel (one geophone) to a multichannel system may be required.

Most newer equipment (manufactured since 1972) uses signal enhancement electronics. This technique allows the stacking of repeatable energy from the seismic energy source, to eliminate the unwanted affects of ambient noise. For most types of engineering investigation, 1-channel to 24-channel equipment is sufficient. For large scale operations, requiring greater depths of investigation, systems of 48 channels to 1,024 channels can be utilized. Obviously, the larger channel systems require more personnel for field operations, and are not as portable (See fig. 13–2).

Small geophones are used to detect the seismic energy. These geophones are available in many different frequencies, and the frequency selected for a particular survey will depend on the objectives of that survey. The normal geophone frequency utilized in most seismic refraction work is 14 Hertz (cycles/second). The geophones are connected to the seismic amplifier by means of a land cable. For multichannel systems, the geophones normally are connected to one cable via different connecting points (takeouts) built into the cable. The takeouts can be built into the cable at different intervals, depending on the spacing required. In normal practice, the takeout spacing (in feet or meters) is specified to the manufacturer when ordering the cable, and the spacing is usually constant along the cable. For engineering seismic refraction surveys, no more than 12 to 24 geophones normally are used per cable.

Other equipment used for seismic refraction surveying may include a blasting machine (shot box) to detonate explosive charges, a magnetic tape recorder to record the seismic data for computer processing, two-way radios, surveying equipment (to provide topographic control and geophone alignment) and miscellaneous reels for the geophone and blasting cables.

Seismic Reflection Surveys

Purpose.—Seismic reflection surveys are performed to provide information on the geological structure within the earth. They do not provide as accurate information on compressional wave velocities as seismic refraction surveys. Historically, seismic reflection surveys have been used successfully in petroleum and geothermal exploration projects; however, they have been used in the past decade to investigate for shallow coal. The information obtained from

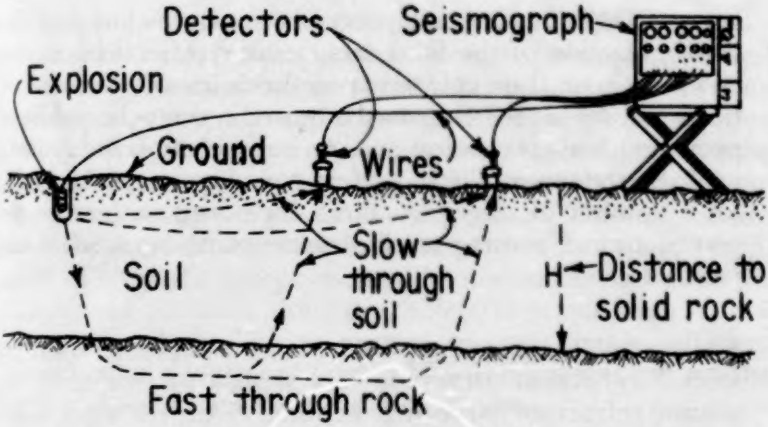


Figure 13-2. – Simplified diagram of seismic refraction test (after Moore, 1961).

seismic reflection surveys can be used to define the geometry of the different subsurface layers, along with faulting data.

Applications.—High resolution seismic reflection surveys have been used on a number of engineering investigations. These surveys provide definitive information on the locations and types of faults, as well as the location of buried channels. Where it is not practical to use seismic refraction surveys, reflection surveys have been used.

Shallow, high resolution seismic reflection surveys are playing an increasingly important role in engineering investigations. Much of the necessary equipment is portable, and with the advent of small computers, data processing routines can be handled easily. When correctly used, seismic reflection surveys may provide certain data that seismic refraction surveys can not, i.e., velocity reversal information. However, compressional wave velocity information derived from reflection surveys may not be as accurate as from refraction surveys. The compressional wave velocities needed for the analysis of the reflection records themselves, from seismic refraction surveys, uphole velocity surveys and from sonic logs.

Seismic reflection surveys have been used since the 1920's for oil exploration. With the advent of the common depth point (CDP) shooting, computer processing techniques and the digitization of the field data, seismic reflection surveys now dominate the exploration methods for oil. Seismic reflection surveys are being used now in the geotechnical field, providing high resolution data on subsurface layering, and geologic structure. These surveys have been used for siting for a number of large structures, including nuclear power plants, tunnel routing studies, mine planning studies and fault studies.

Equipment Requirements.—The basic equipment used for seismic reflection surveys is very similar to that used for seismic refraction surveying. In some cases, the equipment may be identical. For civil engineering investigations, ground-water studies, and mining studies, small portable equipment of up to 24 channels may suffice. For larger investigations, such as petroleum exploration, over 1,000 geophones (and their corresponding amplifiers) may be used.

Almost all seismic reflection data are recorded on magnetic tape, such that the field data may be input into computer systems for direct processing. Tape transport systems may require air conditioning for stability when working in climatically hot areas. This usually is accomplished by mounting the total equipment system in a camper-type housing on a truck body. Smaller, portable reflection systems that are subjected to direct environmental contact should be protected against direct sunlight, heat, humidity, cold and dust. With proper care, these smaller systems will function as well as the larger, truck-mounted, petroleum exploration systems.

The same type of geophones are used in reflection surveying as are used in refraction surveying. Based on the design of the seismic reflection spread, a group of geophones may be used at a single station to filter out unwanted noise and waves. The output of this group of geophones is summed, and used as a single geophone. As an example, a land cable with 12 takeouts may be used to record the responses of 12 groups of geophones, each group containing 6 geophones.

Land cables used in large-scale reflection operations may differ from those used in small-scale reflection and/or refraction operations. Whereas standard land cables normally contain 12 takeouts, special reflection cables (data cables) may only contain two or three takeouts. A series of data cables can be connected together through special junction plugs. In addition to transmitting the geophone data to the amplifiers, the position of the geophones on these cables can be changed by use of a roll-along switch. The use of this switch allows the instrument operator to record a large number of channels (geophones) and automatically advance the geophone positions along the cable(s) in preparation for the next recording. This, of course, assumes that a sufficient number of geophones (groups) have been laid out on the ground and connected to the data cables.

Other equipment used in seismic reflection surveying will include a shot box to detonate explosive charges, or vibrators (small, portable or truck mounted) to act as the energy source. The use of vibrators requires a correlator to correlate the input signal of the seismic source with the geophone response. Most of the seismic energy sources are detonated or activated by a two-way radio system.

Shear Wave Surveys

Purpose.—Shear waves travel through a medium at a slower velocity than compressional waves. Therefore, shear wave arrivals occur after compressional wave arrivals on seismograms, or they are recorded as secondary arrivals as shown on figure 13–3. Note the reversal of the shear wave arrival (SH) for shotpoint A and B. The arrival time is identified easily by overlying the two seismograms as shown in C. Other types of secondary arrivals also exist due to reflections, combinations of reflections and refractions and surface waves. To identify shear wave arrivals, special surveys (field techniques) are used. These survey techniques are designed to suppress compressional wave arrivals and unwanted reflected or refracted wave arrivals. This procedure enhances shear wave arrivals as well as the polarity of the wave energy.

Applications.—For engineering investigations, shear wave velocities are important as they provide information on in situ low strain dynamic properties of a given material. The

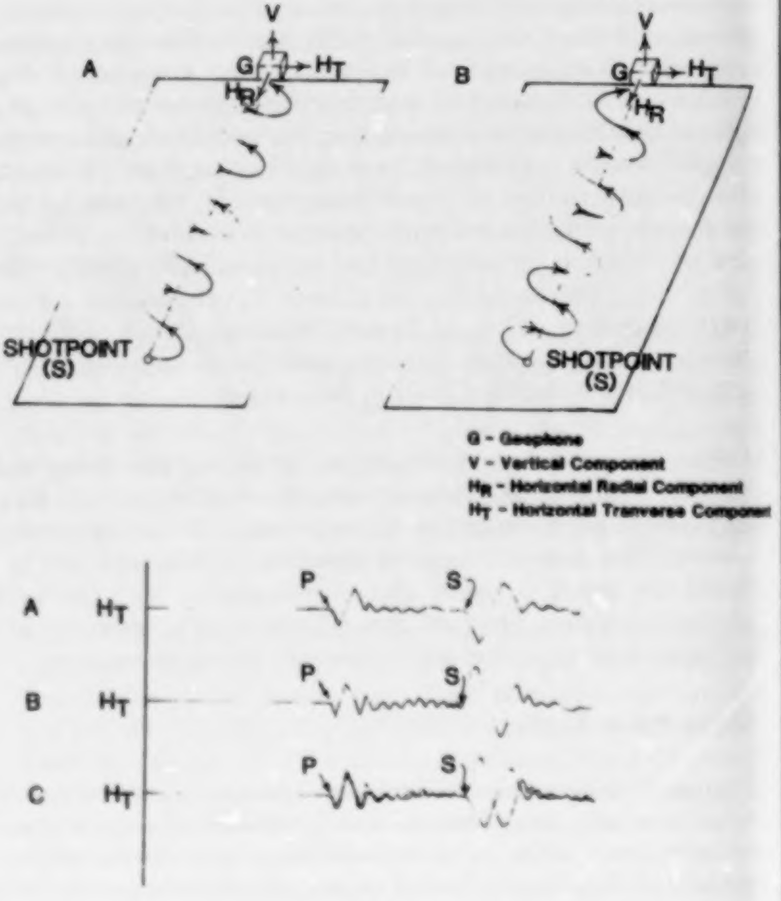


Figure 13-3. – Shear wave seismogram. (SH for surface testing and SV for crosshole investigations).

relationship between compressional wave velocity, shear wave velocity, density and in situ dynamic properties of a given material is shown in table 13–1. The compressional wave velocity can be determined from refraction surveys, the shear wave velocity from shear wave surveys and the density from borehole geophysics or laboratory testing. A common procedure used to determine material dynamic properties at and depth is the crosshole seismic method. Compressional waves (P) and shear waves (SV) are generated in one drill hole and the seismic wave arrivals are received in companion drill hole(s). The seismic source(s) and re-

Table 13-1. – The determination of moduli and ratios for typical velocities of earth materials from refraction surveys.

V_p = Compressional wave velocity (ft/s) (m/s)
V_s = Shear wave velocity (ft/s) (m/s)
E = Young's Modulus (lb/in^2) (MPa)
G = Shear Modulus (lb/in^2) (MPa)
K = Bulk Modulus (lb/in^2) (MPa)
μ = Poisson's Ratio
ρ = Density (in situ) (lb$_m$/ft^3) (kg/m^3)

Shear Modulus: $G = \rho Vs^2$
Young's Modulus: $E = 2G(1 + \sigma)$
Bulk Modulus: $K = \rho(V_p^2\text{-}4/3V_s^2)$
Velocity Ratio: V_p/V_s
Poisson's Ratio: $\mu = (0.5)\ [V_p/V_s]^2\text{-}2/[V_p/V_s]^2\text{-}1$

Typical velocities of earth materials for refraction

Material	Velocity (ft/s)	(m/s)
Dry silt, sand, loose gravel, loam, loose rock, talus, and moist fine-grained topsoil	600-2500	183-762
Compact till; indurated clays; gravel below water table,* compact clayey gravel, cemented, sand, and sand-clay	2500-7500	762-2287
Rock, weathered, fractured, or partly decomposed	2000-10,000	610-3049

Table 13-1. – The determination of moduli and ratios for typical velocities of earth materials from refraction surveys.—Continued

Material	Velocity (ft/s)	(m/s)
Shale, sound	2500-11,000	762-3354
Sandstone, sound	5000-14,000	1524-4268
Limestone, chalk, sound	6000-20,000	1829-6098
Igneous rock, sound	12,000-20,000	3659-6098
Metamorphic rock, sound	10,000-16,000	3049-4878

*Velocity of sound in water is about 4,700 ft/s (1433 m/s) and all fully saturated materials should have velocities equal to or exceeding this values.

ceiver(s) are maintained at equal depths (elevations) for each recording. Drill hole deviation surveys are performed in each drill hole to determine the distances between each of the drill holes at all recording intervals. For typical seismic velocities of earth materials, see table 13–1.

Additionally, shear wave surveys are used for exploration surveys for both engineering and oil and gas investigations. Because shear waves are slower than compressional waves, in some cases shear wave surveys can provide better resolution of subsurface conditions than compressional wave surveys (for reflections).

Equipment Requirements.—The equipment used in seismic refraction and reflection surveying also can be used in shear wave refraction and reflection surveying. However, horizontally oriented geophones are used to record shear wave arrivals. These geophones have a lower natural frequency than those geophones used in normal refraction/reflection surveying. For crosshole investigations, vertically oriented geophones clamped against the casing wall are used to detect the shear wave arrival (SV); hydrophones are used to detect the compressional wave arrival.

Surface Waves

Purpose.—Surface wave surveys are designed to produce and record surface waves and their characteristics. Surface waves are the slowest type of seismic wave, traveling along the boundaries between different materials. There are a number of different types of surface waves, such that in addition to recording the waves, a determination of their characteristics must also be made. Normally, surface waves are filtered out of seismic data, or are ignored. The term "ground roll" in the oil exploration industry denotes surface waves. Special care is taken in seismic reflection surveys to filter out surface waves, as if they are not filtered out they can interfere with desired reflections.

Surface waves are created by the constructive and destructive interference of refracted and reflected seismic waves. Surface waves, in addition to having the slowest velocities of all seismic waves, have lower frequencies and higher amplitudes than other seismic waves. Surface waves that travel along the boundaries with a body are called Stonley waves.

The different types of surface waves and their characteristic motions are show in figure 13–4.

Applications.—The principal application of surface wave surveying for geotechnical investigations is to determine the type and characteristics of surface waves that can exist at a given site. This information is useful for determining preferred site frequencies, and for earthquake design analysis.

Equipment Requirements.—The cables and amplifiers used in normal refraction surveying can be used in surface wave surveying. Normally, special geophones are used, when available. These geophones contain three components (Vertical, Horizontal Transverse and Horizontal Radial – transverse and radial signifying the orientation of the geophone in respect to the source of seismic energy). Surface wave geophones are of lower frequency than normal refraction/reflection geophones, the frequency ranging from 1 to 5 Hertz. If such geophones are not available normal refraction/reflection geophones can be used, but special care must be taken. Vertical geophones can be used as the vertical

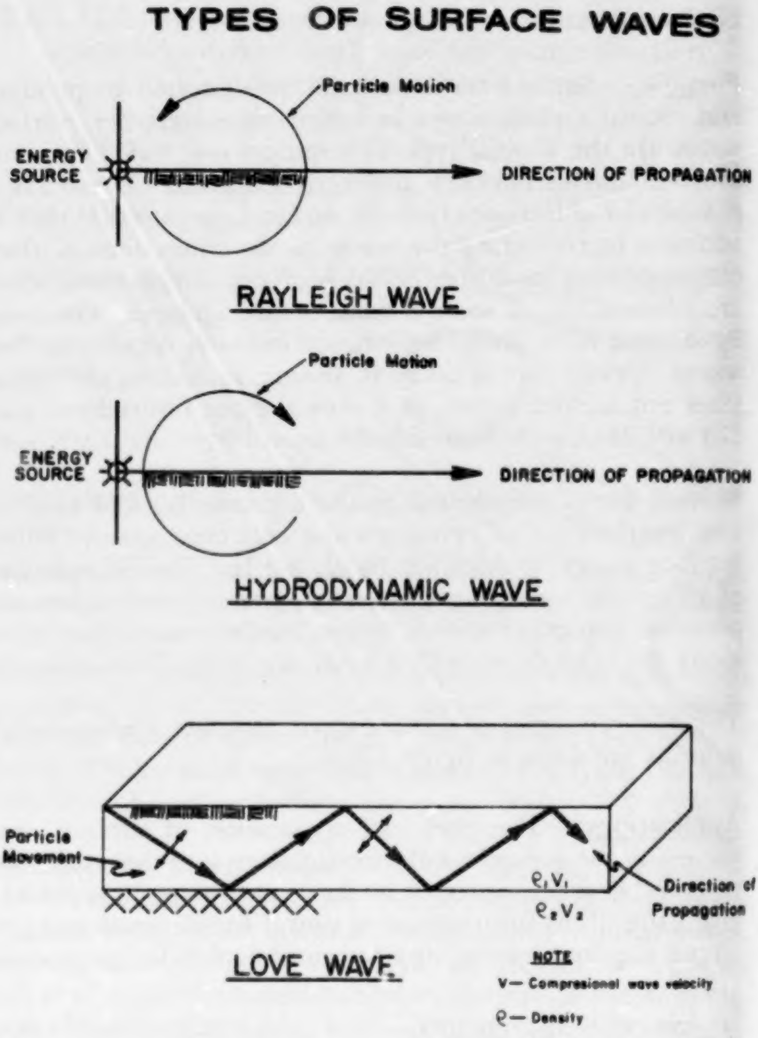


Figure 13-4. – Types of surface waves.

component, and horizontal geophones (such as used in shear wave surveying) can be used for both radial and transverse components.

Vibration Surveys

Purpose.—Vibration surveys are performed to measure the vibrational levels produced by mechanical or explosive sources. Once these levels are determined, procedures can be designed to reduce the possibility of vibrational damages.

Applications.—Vibrational surveys have been performed in conjunction with quarrying and mining operations, during excavations, to measure the effects of traffic on sensitive equipment and to measure the effects of aircraft (sonic vibrations) on urban areas and on historical buildings.

Many manufacturing and research facilities contain extremely sensitive equipment with very specific vibration tolerances. In the event of nearby construction, vibration surveys can be very useful in determining the exact limits of allowable vibration and in designing procedures to both reduce the vibrational levels and maintain construction progress. The same type of vibration survey can be used in quarrying and/or mining operations to reduce the vibrational levels and yet maintain rock breakage and fragmentation.

Equipment Requirements.—A number of different firms manufacture equipment designed specifically for vibration surveys. Most of this equipment is very similar, in that it contains a special geophone, an amplifier, and paper recorder and will have an optional magnetic tape recorder and a sound meter. The geophones are three component, low frequency geophones, similar (or the same) to those used in surface wave surveys. Most equipment is capable of recording ground motion in terms of particle displacement, velocity or acceleration. Some equipment only records on magnetic tape, which then must be sent to the manufacturer for interpretation.

Electrical Resistivity Profiling Surveys

Purpose.—Electrical resistivity profiling is based on the measurement of lateral changes in the electrical properties of subsurface materials. The electrical resistivity of any material depends on its porosity and the salinity of the water in the pore spaces. Although the electrical resistivity of a material may not be diagnostic of that material, certain materials can be classified as having specific ranges of electrical resistivities. In all electrical resistivity surveying techniques, an electrical current of known intensity is input into the ground through two (or more) electrodes. The separation between these current electrodes depends on the type of surveying being performed and the required depth of investigation. The potential voltage of the electrical field resulting from the application of the current is measured between two (or more) other electrodes at various locations. Since the current is known, and the potential can be measured, an apparent resistivity can be calculated.

Applications.—Electrical resistivity profiling is used to detect lateral changes in the electrical properties of subsurface material, usually to a specified depth. This technique has been used to map the lateral extent of sand and gravel deposits, to provide information for cathodic protection of underground utilities, to map the lateral extent of contamination plumes (in toxic waste studies) and in fault exploration studies. For representatives values of resistivity, see table 13–2.

Equipment Requirements.—Almost all electrical resistivity surveying equipment consists of a current transmitter, a receiver (to measure the resulting potential), two (or more) current electrodes and two (or more) potential electrodes. Two types of current transmitters are available for use, direct current and alternating current. Direct current transmitters are powered by dry cell or nickel-cadmium battery systems, and are limited in their output, however they are very portable for field work. Alternating current transmitters have a more powerful output range, hence a greater depth penetration, but they are not very portable, as the

Table 13-2. – Representative values of resistivity.

Material	Resistivity (ohm-m)
Clay and saturated silt	0-100
Sandy clay and wet silty sand	100-250
Clayey sand and saturated sand	250-500
Sand	500-1500
Gravel	1500-5000
Weathered rock	1000-2000
Sound rock	1500-40000

power source is usually a generator. Recent innovations in transmitter design have included the use of pulsing direct current input to the current electrodes. This system, in effect, acts as a signal enhancement.

Most current and potential electrodes are metallic, usually stainless or copper clad steel. Where natural earth currents, or electrochemical reactions affect the potential electrodes, non-polarizable electrodes must be used to measure the potentials resulting from the current input. These non-polarizable electrodes consists of a plastic or porcelain container with an unglazed porous bottom. The container is filled with a metallic salt solution which is in contact with a rod of the same metal. Copper sulfate salt in solution commonly is used with a copper rod.

The electrodes are connected to the transmitter and receiver by cables, which are usually contained on small portable reels.

Electrical Resistivity Sounding

Purpose.—Electrical resistivity sounding is based on the measurement of vertical changes in the electrical properties of subsurface materials. In contrast to resistivity profiling, in which the electrode separation is fixed, the electrode spacing used for resistivity sounding is variable, while the center point of the electrode array remains constant. The depth of investigation increases in a general sense as the electrode spacing increases, thus resistivity soundings are used to investigate variations of resistivity with depth.

Applications.—Electrical resistivity soundings (often referred to as VES, Vertical Electrical Sounding) are commonly used for aquifer and aquaclude delineation in ground water investigations. They have been used for bedrock delineation studies, where there may not be a sufficient velocity contrast to permit seismic surveying. Vertical electrical soundings have been used for large scale mineral investigations, geothermal investigations, cathodic protection studies, and recently have found rather widespread application in toxic waste studies.

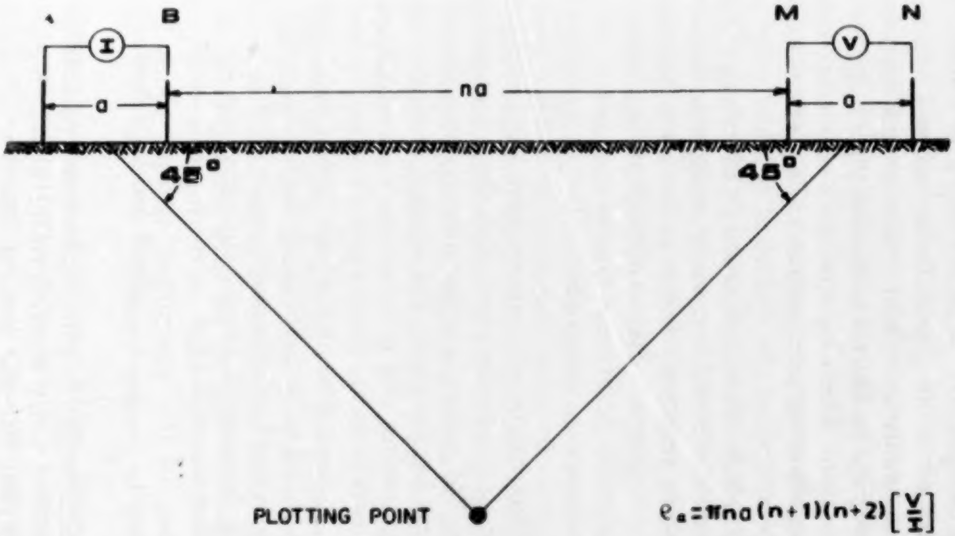
Equipment Requirements.—The equipment used in resistivity sounding is identical to the equipment used in electrical resistivity profiling. For shallow investigations a DC transmitter is normally sufficient, whereas for deeper investigations an AC transmitter may be required.

Electrical Resistivity Dipole-Dipole Surveying

Purpose.—Dipole-dipole surveying refers to the electrode array orientation, whereby the pair of potential electrodes may have any position with respect to the pair of current electrodes. When the current and potential electrodes are positioned along the same line, the array is referred to as an axial dipole array (fig. 13–5). The current electrodes are separated from the potential electrodes by an interval, *n*, which is some multiple of the current and potential electrodes separation, *a*. Normally, the separation of the current and potential electrodes will be equal. Dipole-dipole arrays are used to determine both the lateral and vertical changes in electrical properties of the subsurface materials with one electrode array.

Applications.—The dipole-dipole array has limited applications in engineering and ground-water geophysics. This type of electrode array has been used primarily in mineral and geothermal exploration. It has been applied to studies for the delineation of abandoned mines, mapping salt-fresh water interfaces, and mapping buried stream channels. Dipole-dipole arrays will probably have an important role in toxic waste investigation programs.

Equipment Requirements.—The equipment used in dipole-dipole surveying is, in most parts, identical to that used in other types of resistivity surveying. However, since the current and potential electrodes are separated by a distance, it is preferable to have the transmitter and receiver as individual units. Thus, the cable requirements are much less than other types of resistivity surveying, as the only cables needed are for the connections between the current electrodes, and between the potential electrodes. Since the distance of separation between the current and potential electrodes may be large, dipole-dipole surveying normally requires more transmitter power than either resistivity



$$\rho_a = \pi na(n+1)(n+2)\left[\frac{V}{I}\right]$$

Where ρ_a = apparent resistivity
n = integer multiple (1, 2, 3..)
a = electrode spacing
V = voltage
I = current

LEGEND

A, B – Current Electrodes
M, N – Potential Electrodes
a – Electrode Separation
I – Current Source
V – Voltmeter

Figure 13-5. – Dipole resistivity array.

sounding or profiling surveys, hence a generator may be required for the transmitter.

Electromagnetic Conductivity Profiling Surveys

Purpose.—Electromagnetic (EM) surveying uses time-varying, low frequency electromagnetic fields induced into the earth. Basically, a transmitter and receiver and a buried conductor are coupled by electrical circuitry through electromagnetic induction. The characteristics of electromagnetic wave propagation and attenuation on a given site can permit an interpretation of the electrical conductivities of the subsurface materials. Since electrical conductivity is the reciprocal of electrical resistivity, electromagnetic surveys are used to provide resistivity information on subsurface materials. Electromagnetic conductivity profiling surveys are specifically used to determine lateral changes in conductivity of the subsurface materials.

Applications.—Electromagnetic surveys have been used primarily for mineral exploration, and with the exception of magnetic surveys, EM surveys are the most commonly used geophysical surveys for minerals. EM surveys recently have been used in engineering and ground-water investigations. They have been used to locate buried pipes and cables, and, in the military, to locate near-surface landmines. The method has been found to be particularly useful in mapping contaminant plumes and buried metallic waste (such as metal drums containing hazardous chemicals). EM surveys are suited to hazardous waste studies, as during the surveying procedure no part of the equipment systems touch the ground (which may be contaminated).

Equipment Requirements.—The technique requires sophisticated equipment which consists of a transmitting coil that induces a current into the ground. The receiving coil senses the magnetic field generated by the induced current, as well as the primary field generated by the transmitter. Under certain constraints, the ratio of the induced secondary field to the primary field is linearly proportional to the earth conductivity.

Currently, there are two types of systems, fixed coil spacing and variable coil spacing. The coil spacing determines the effective depth of investigation. The fixed spacing equipment can be operated by a single person, but, due to the relatively small coil spacing is only useful for shallow surveys. Other equipment is available which can be used at different spacings and which, therefore, can be used to investigate materials at various depths. The depths, however, are limited to a pre-selected range, which is based on coil tuning restrictions and other conditions which must be met to maintain a linear relationship with the earth's conductivity field.

Electromagnetic Conductivity Sounding Surveys

Purpose.—The basic principles for EM surveying have been discussed in the previous section. Electromagnetic Sounding surveys are used to determine vertical changes in conductivity of subsurface material.

Applications.—Electromagnetic sounding surveys have been applied to delineate areas of permafrost, gravel deposits, mapping bedrock topography and to provide general geological information. EM sounding and profiling surveys have been applied to mapping areas of salt water intrusion (in coastal regions), archaeological investigations, and fault studies.

Equipment Requirements.—The equipment used in EM sounding surveys is the same as that used in EM profiling surveys. For shallow investigations, less sophisticated equipment is required than for deeper investigations.

Ground Probing Radar

Purpose.—Ground probing radar surveys have the same general characteristics as seismic surveys. However, the depth of investigation with radar is extremely shallow when compared to seismic survey. This disadvantage is partially offset, however, by the much greater size-resolution of the radar techniques.

Applications.—Ground probing radar surveys can be used for a variety of very shallow engineering problems, including the locations of pipes or other buried manmade objects, the very high resolution mapping of near-surface geology, the location of near-surface cavities, and the location and extent of piping due to deeper sink-hole activity, or leakage in dams.

These applications are limited by the very small depth of penetration which is usually possible with the very high frequencies involved in radar. Silts, clays, salts, saline water, the water table, and any other conductive materials in the subsurface, will severely restrict or even preclude any further penetration of the subsurface by the radar pulses.

Equipment Requirements.—The equipment for ground probing radar is manufactured by two or three companies. Therefore, the present sources for equipment and contract services are extremely limited. Currently Reclamation maintains a ground probing radar unit.

The equipment consists of an antenna/receiver sled, a control/signal processor unit, a strip chart recorder, and a power supply, plus various accessories such as a tape recorder, and special signal analyzers. Normally this equipment would be operated from a vehicle, except for the antenna/receiver sled which can be either towed behind the vehicle, or hand pulled.

This equipment normally will have several antenna/receivers with different frequencies of operation. The higher frequencies will give greater resolution at the expense of depth penetration. A schematic diagram of radar operations is shown in figure 13-6.

Self Potential Surveying

Purpose.—Self potential (SP), spontaneous potential or natural potential is a natural electrical potential existing within the earth which arises from a number of causes. These causes can be classified broadly into two groups (excluding man-made causes):

- Mineralization Potential.—Mineralization potential is primarily the result of chemical concentration cells formed when conductive mineral deposits, such as graphite or sulfide, are intersected by the water table.

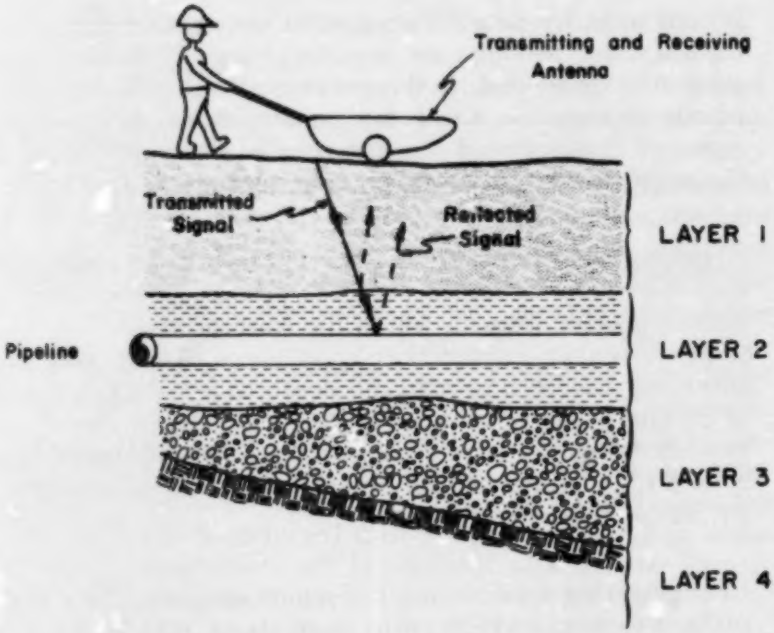


Figure 13-6. – Ground penetrating radar schematic.

- Background Potential.—Background potential primarily is a result of: (a) two electrolytes of different concentration being in contact with one another; (b) electrolytes flowing through a capillary system or porous media; (c) an electrolyte in contact with a solid; and (d) electromagnetically induced telluric currents.

Mineralization potentials are almost always negative, and may have values up to several hundred millivolts. Background potentials can be either positive or negative, and usually have values of only a few tens of millivolts.

The background potentials developed by electrolytes flowing through a capillary system or porous media (called electro-filtration or streaming potentials), are used for the study of seepage. As water flows through a capillary system, it collects and transports positive ions from the surrounding materials. The positive ions accumulate at the exit point of the capillary, leaving a net positive charge. The untransported negative ions accumulate at the entry point of the capillary, thus leaving a net negative charge. If the streaming potentials developed by this process are of sufficient magnitude to measure, the entry point and the exit point of zones of concentrated seepage may be determined due to the respective negative and positive self potential anomalies.

Applications.—Self potential surveys have been applied to map the lateral extent of mineral deposits, and in some instances provide information of the configuration of the deposits. Another exploration application of self potential surveying has been to map the depth to and configuration of certain geothermal areas in the world. Normally, in the geothermal exploration application, self potential surveying is used in conjunction with other geophysical surveys (gravity, seismic and electrical).

In engineering applications, self potential surveys have been utilized to map leakage paths from dams, both in the reservoir area and along the crest, toe and abutments. Self potential surveying has also been used to map leaks from canals and buried pipelines that transport liquids. Detachment walls and lateral limits of some landslide masses have been mapped with self potential surveys. Self potential surveying may play an important role in contaminated waste studies (contaminant plume mapping), and in monitoring leakage from hazardous waste sites and dams.

Equipment Requirements.—The basic piece of equipment required for self potential surveying is a voltmeter. Analog voltmeters can be used, however since very small potentials are being sought, it is preferable to utilize a digital voltmeter or multimeter. Self potentials are detected by the use of two nonpolarizable electrodes which are embedded in soil or water. Nonpolarizable electrodes are used to prevent electrode potentials from development, since electrode potentials can be larger than the self potentials sought. The two nonpolarizable electrodes are connected to the voltmeter (multimeter) by single conductor, jacketed cable. Theoretically this cable may be any length, but cable resistance must be taken into account, such that normally the length of cable used varies from 1,000 to 2,000 feet (305 to 610 meters).

Magnetic Surveying

Purpose.—Magnetic surveys are performed to measure anomalous conditions within the earth's magnetic field. Once these anomalous conditions are detected and measured, the cause of the anomaly is sought by interpretation of the data. The earth's magnetic field resembles the field of a bar magnet. The field is twice as large at the polar regions than at the equator.The intensity of the field in the polar regions is approximately 60,000 gammas, while at the equator it is approximately 30,000 gammas. The earth's magnetic field is not symmetrical, but contains many large perturbations due to local variations in magnetic materials, and larger magnetic features. Within the earth's field, anomalies on the order of one gamma to several thousand gammas are being sought by magnetic surveys. The smaller anomalies can be detected with complex instruments, while the larger anomalies will be defined with simpler instruments and field techniques.

Applications.—Magnetic surveys have their widest applications in petroleum and mineral exploration programs. All rocks have magnetite content, and depending on the percentage of magnetite, certain rock types can be mapped by magnetic surveys. For applications in petroleum exploration, the geological aspects are somewhat simpler as the sources of most magnetic anomalies lie within the basement complex, such that the overlying sediments are often "transparent" to magnetic surveys.

In civil engineering applications, magnetic surveys have been widely applied to detect buried barrels of contaminated materials, and to detect and map buried pipelines. Magnetic surveys have been widely used in archaeological investigations.

Equipment Requirements.—Several types of instruments are available to perform magnetic surveys. They range from mechanical devices for measuring the vertical or horizontal intensity of the earth's field, to very sensitive, non-mechanical instruments which measure the total field intensity. For the more sensitive the instruments, more time and care is required to set up and orient the instrument.

Field balances and dip needles are mechanical systems that contain pivoted magnets and react to large changes in the vertical or horizontal intensity of the earth's field. Fluxgate magnetometers contain a magnetically saturated core, and when held in the vertical position will detect vertical changes in the earth's field. Depending on the sensitivity of the instrument, changes of one gamma can be measured, although it is more common to use fluxgate magnetometers to detect changes on the order of tens of gammas. The proton magnetometer has a greater sensitivity than the fluxgate, contains no moving parts, and measures the total field intensity without errors which might result from coil orientation.

Gravity Surveys

Purpose.—Gravity anomalies are the direct result of horizontal contrasts in densities of materials in the earth. If all the materials within the earth were layered horizontally and were of uniform density, there would be no density contrasts. Density contrasts of different materials are controlled by a number of different factors, the most important are the grain density of the particles forming the material, the porosity of the material and the interstitial fluids within the material. Generally, soil and shales specific gravities range from 1.7 to 2.2. Massive limestone specific gravities average 2.7. While this range of values may appear to be fairly large, local contrasts will be only a fraction of this range. A common order of magnitude for local density contrasts is 0.25.

Density contrasts can be determined by calculating the gravity effect of a known model and comparing that effect with the observed gravity, as determined from a gravity survey.

Applications.—Gravity surveys provide an inexpensive determination of regional structures that may be associated with ground-water aquifers or petroleum exploration targets. Historically, gravity surveys have been one of the principal exploration tools in regional petroleum exploration surveys. Gravity surveys have applications in engineering investigations, although somewhat limited in scope. They have been used to obtain information on bedrock depths and the top of rock configuration in areas where it has not been possible or practical to use other geophysical surveys techniques. Microgravity (high precision) surveys have been used in a few instances to obtain information related to the success of grouting programs. In these cases, microgravity surveys are performed prior to and after grouting operations, and density contrasts of the two surveys are compared. Microgravity suveys have been used for archaeological investigations.

Equipment Requirements.—Gravity meters generally are classified as one of three types, a mass on a spring, a torsion fiber, or a zero length spring. This classification is based on the mechanical design of the instrument. A mass on a spring instrument is designed such that a change in the length of the spring is proportional to the small change of a total force, which is the same proportionally as the small change in total measured gravity. In torsion fiber instruments, the mass is attached to an arm which is horizontally supported by delicate torsion fibers. The mass supporting arm is adjusted whereby its torque is nearly equal to the torque of the supporting torsion fibers. Differences in observed gravity are proportional to the adjustment made. Zero length spring instruments are designed such that an initial stress is needed before the coils of the spring supporting the mass separate. The stress strain curve for the spring is projected back to zero, as if the spring has no length. The actual spring deflection is proportional to the small change in observed gravity.

All gravity meters are of rugged construction, as they house very sensitive components, and they must remain reliable in field use. All instruments have some drift due to small changes inherent in the spring constant. Gravity meters are temperature sensitive, and as such they are temperature compensated by a thermostat and electrical power source. Temperature compensation usually requires that the gravity meter be housed in a vacuum container to assure that all moving systems have the same accuracy at the same temperature.

The unit of acceleration is termed the *gal* (after Galileo). One gal is equal to one centimeter per second squared (cm/sec^2). The average acceleration on the earth's surface is 980 cm/sec^2. Most gravity meters are built to have a precision of 0.05 gal. Microgravity meters have an even higher precision.

Project Planning Checklist

The following is a project planning checklist designed to aid both project personnel and the project geophysicist in planning and performing geophysical surveys.

Project Definition

(1) Job File (General Administration).—Does the project file contain the following information:

____ ____ ____ Project Number
____ ____ ____ Project Engineer Name and Contact Phone
____ ____ ____ Project Job Location
____ ____ ____ Project Manager
____ ____ ____ Project Geologist
____ ____ ____ Project Geophysicist
____ ____ ____ Geophysical Field Crew Composition

(2) Project File (Geotechnical).—Does the project job file contain the following geotechnical information:

____ ____ ____ Purpose of Survey
____ ____ ____ Depth to target (bedrock, water table)
____ ____ ____ Desired accuracy in the data
____ ____ ____ Location of the site: geographically, geologically, and culturally

(3) Site Vicinity.—Location of:

____ ____ ____ Houses
____ ____ ____ Roads
____ ____ ____ Railroads
____ ____ ____ Power lines
____ ____ ____ Underground utilities
____ ____ ____ Pipelines
____ ____ ____ Water wells

____ ____ ____ Radio transmission towers
____ ____ ____ Local noise sources (power plants, quarries, compressors)

(4) Site Ground Surface.—Description of:
____ ____ ____ Natural site or landfill
____ ____ ____ Soil types
____ ____ ____ Swamps, lakes or streams
____ ____ ____ Vegetation, clear, plowed field, heavy brush, trees
____ ____ ____ Accessibility (car, foot) fences, ditches
____ ____ ____ Topography (sand dunes, flat, irregular or extreme)
____ ____ ____ Land ownership (restricted areas)
____ ____ ____ Climatic conditions expected during course of survey

(5) Subsurface Conditions.—Information on:

____ ____ ____ Depth to water table
____ ____ ____ Character of near-surface materials
____ ____ ____ Character of materials down to target
____ ____ ____ Description of target (age, consolidation, erosional features)
____ ____ ____ Geologic history of the area
____ ____ ____ Existing and planned borings

(6) Additional Information.—What other requirements are planned for the site, and what information will result from them.

Not all the above information will be in the job file at this state, but the more data available, the easier it will be to make an estimate of time, materials and expenses that will be involved in the completion of the investigation. Much of the above data can be obtained from maps and any existing boring logs.

Geophysical Services and Geophysical Equipment Capabilities

This provides information on the available services and equipment and equipment capabilities and requirements for geophysical investigations conducted by or coordinated by the Geology Branch, Geophysics Section.

Borehole Geophysical Logging

The Geophysics Section has a geophysical borehole logging truck equipped to obtain in situ measurements on various foundation properties and borehole parameters. The geophysical logs can be used to validate and supplement drill hole logs or can be used exclusively when coring is considered unnecessary, impractical, or too expensive.

The logging system is truck mounted, equipped with a portable gas-powered generator, and functions as an independent unit.

The logging unit is equipped with a seven-conductor, double strand 5/16-inch steel cable and has a total depth capability of 3,000 feet (915 meters). The cable and downhole probes are capable of withstanding temperature up to 250°F (121°C) and hydrostatic pressure up to 10,000 lb/in^2 (68 kPa). While no minimum borehole depth is established, generally boreholes less than 30 feet (10 meters) deep are impractical to log due to the length of the downhole probes which are as long as 20 feet (6 meters).

Time required for logging depends on borehole depth and condition and the number and type of logs required. In moderately deep holes (150 to 500 feet) [46 to 152 meters], each logging mass including setup time requires approximately one hour. Cost for the borehole logging truck and operator is approximately $300 per 8-hour day, including travel and per diem (1988 prices).

Generally, the best logs are obtained from uncased, fluid-filled boreholes. However, several types of logs, when run inside steel or PVC casing, usually will produce good results. Since borehole parameters such as variations in borehole diameter, the presence of various drill muds or fluids, and casing or grout severely affects many of the logs, a detailed description of the borehole completion is necessary for correct interpretation of the logs. Table B-1 (Appendix B) provides a listing of the log types which are presently available and an indication of any restrictions or borehole completion requirements.

If you have any questions regarding specific applications or scheduling, please contact personnel in the Seismotectonics and Geophysics Section in the Geology Branch, telephone 303-236-4196.

Equipment Used or Furnished by the Geophysics Section

Seismic Equipment.—

(a) Seismographs.—The following seismographs are maintained by the Geophysics Section:

- 24-channel portable refraction seismograph system, EG and G Geometrics ES-2415F with DMT-911 digital tape recorder. Self-contained power source and built-in blaster.

- 12-channel portable signal enhancement seismograph system, geoMetrics/nimbus ES-1210F with CRT display and built-in drywrite recorder. Powerpack, blaster, and digital (nine-track) tape recorder.

- 6-channel portable signal enhancement seismograph system, Bison 1580, with CRT display and SIE R6 drywrite recorder. Self-contained power source and blaster.

  Uses: Seismic refraction, reflection, uphole, downhole, and crosshole methods.

- 4-channel portable engineering seismograph system, Sprengnether VS-1200, with built-in drywrite recorder and self-contained power source. Orthogonal seismometer with 2,100 feet (640 meters) of cable.

  Uses: Blast vibration monitoring, ambient seismic noise monitoring, and site selection and elevation.

(b) Geophone Cables for Surface Surveys.—Portable geophone cables with 12 takeouts and 50-foot (15 meters) leader wire on each end. Available with the following takeout spacing:

One 5-foot
Two 20-foot
Two 50-foot
Two 100-foot

Four 1-meter
Four 5-meter
Two 15-meter
Four 30-meter

Thirteen 3-foot (1 meter) cables with three takeouts for grouping geophones. Use with above cables.

Two 100-foot (30 meters) extension cables.
One 600-foot (183 meters) extension cables.

(c) Sensors for Surface Surveys.—Seventy-five vertical geophones, Mark Products L-1. Fourteen horizontal geophones, Mark Products L-1H.

(d) Sensors for Downhole Surveys.—One velocity cable with 12 hydrophones at 10 foot (3 meters) spacing. Requires 3-inch-minimum (75 mm) diameter, fluid-filled hole; maximum depth 500 feet (152 meters).

One shallow well seismometer, three detectors, orthagonal, Mark Products L-1-3DS. Required 5-inch (127.5 mm) minimum-diameter hole; maximum depth 50 feet (15 meters).

Two sidewall-clamped geophones, three detectors, orthagonal, Mark Products L-10-3D. Required 3-inch (75 mm) minimum-diameter hole; maximum depth 500 feet (152 meters).

(e) Sources for Surface Surveys.—Three sledge hammers with solid-state triggers.

Three EBW (Exploding Bridgewire) blasting sets—one modified for radio shooting.

One Betsy shotgun source, weight 250 pounds (113 kg).

(f) Sources for Downhole Surveys.—One sparker, Simplex 1000 joule. Requires 2-inch (50 mm) minimum diameter, fluid-filled hole; maximum depth 500 feet (152 meters).

One Bison downhole hammer. Requires minimum hole diameter of 4 inches (100 mm); maximum depth 500 feet (152 meters).

Resistivity Systems (Including Self-Potential).—

(a) Shallow Survey Equipment (0 to 100 feet (30 meters)[1].—One Soiltest R50/60, output 750 volts, separate transmitter and receiver, rechargeable transmitter (16 pounds [7.26 kg]).

One Bison 2350A, output 540 volts, transmitter and receiver in same case (14 pounds) [6.35 kg].

One Bison 2350B, output 720 volts, transmitter and receiver in same case (14 pounds) [6.35 kg].

(b) Medium Depth Survey Equipment (0 to 300 feet [91.5 meters])[1].—One Bison 2390, output 1000 volts, separate transmitter and receiver, both rechargeable (16 pounds each [7.25 kg]).

(c) Deep Survey Equipment (0 to 1,000 feet [300 meters] or more)[1].—One Geotronics, output 5000 volts, FT-10 transmitter (85 pounds [38.6 kg]), R-401, receiver (10 pounds) [4.5 kg], B-2 generator (160 pounds [72.5 kg]), rechargeable receiver.

Corrosion and ground mat surveys
Depth to sand, gravel, bedrock, or water-saturated layers
Geothermal exploration (deep soundings)

---

[1] Depth using Wenner arrays and depends on soil and/or rock resistivities. Uses: Soundings determine variation of resistivity with depth and thickness of layers.

Profiling determines lateral variations in resistivity:

Sand and gravel deposits
Faults and fault zones
Abrupt horizontal changes in types of earth materials

(d) Self-potential (SP) Systems.—Consists of highly accurate digital voltmeter, several porous electrodes, and enough copper wire to survey large embankment structures and/or foundations while maintaining a single base station. SP surveys are used for determining possible seepage paths. There is some indication that SP surveys may also be used to delineate deep fissures or cavities.

Electromagnetic Conductivity System.—

(a) Electromagnetic (EM) Conductivity Survey Equipment.—Geonics Model EM-34 Terrain Conductivity Meter has capability to measure ground conductivity (reciprocal of resistivity) to depths of approximately 50, 100, and 200 feet (15, 30, and 60 m) using two loop antennas (no other stakes or probes are required). The EM-34 provides very rapid conductivity profiles which may be converted into resistivity profiles.

Borehole Logging Equipment.—

(a) Portaloggers.—Widco Model PLS-PRG, records natural gamma, self-potential, and single resistance. Requires a minimum hole diameter of 1-1/2 inches (3.38 mm), fluid-filled for self-potential and resistance. Portable battery powered. Maximum depth 1,000 feet (305 m).

Geoenergy Model No. 1 single-conductor, portable, battery-powered, logging system. Records natural gamma, self-potential, and single point resistance; requires 1-1/2-inch (3.38 mm) minimum-diameter hole, hole must be fluid-filled and uncased for SP and resistance. Maximum depth 500 feet (152 m).

Geoenergy Model No. 2 four-conductor, portable, battery-powered, logging system. Records natural gamma, SP, and single point resistance; requirements for hole conditions and depth are same as Model No. 1 above.

(b) Logging Trucks.—Comprobe truck-mounted logger on 1983 1-ton (2032 kg) Chevrolet Suburban. Records natural gamma, self-potential, single point resistance, caliper, density, and neutron. Requires 3-inch (75 mm) minimum-diameter hole, must be fluid-filled for self-potential and resistance. Maximum depth 3,000 feet (915 meters).

Comprobe truck-mounted logger on 1977 International. Complete logging functions. See "Geophysical Borehole Logging Capabilities" for details.

Miscellaneous Equipment.—

(a) Borehole Television Cameras.—Sperry Model 3000, truck-mounted. Requires 2-inch (75 mm) minimum-diameter, dry or clear water-filled hole; maximum depth 2,000 feet (610 meters), 1,600 ft in water (488 meters).

Rees model R93, portable. Requires a minimum hole diameter of 1-7/8 inches (48 mm), either dry or filled with clear water; maximum depth 650 feet (198 meters).

Uses: Geologic boreholes.—Surveys for core orientation, determination of dip and strike of planar structures intercepting a borehole, examination of areas of high core loss.

Water wells and inclinometers.—Surveys for determination of casing and screen condition, iron bacteria, or other problems.

Horizontal pipes or drains.—Surveys for joint continuity, breaks, or alignment. Deflection measurements in 10-inch (255 millimeters) and larger drain tubing.

(b) Temperature Logger.—Reclamation-designed, portable, self-contained, accuracy to one-hundredth degree. Requires 3/4-inch (19 millimeters) diameter hole. Two with 500-foot (152 meters) and one with 1,000 foot (305 meter) deep capabilities. Uses: Temperature surveys for gradients, aquifers, ice lenses, geothermal.

(c) Borescope.—National Statham, Inc. Requires 1-1/4-inch minimum (32 millimeters) diameter hole, dry or clear water filled. Maximum depth 46.5 feet (14 meters).

(d) Fluorometer.—Turner model 111, with automatic servo balancing for fluorescence measurements. Requires 110 volts.

(e) Magnetometer.—McPhar model M700, battery operated, vertical field magnetometer. Uses: Deep basement studies, definition of magnetic subsurface features (near surface), and delineation of igneous intrusive features.

(f) Borehole Deviation Survey System. OWL Model 781, capable of directional readings 0° to 359° inclination range, full sphere. Requires minimum hole diameter of 2 inches (50 millimeters), bearing measurements cannot be performed inside steel casing. Uses: Provides borehole direction and inclination information for accurate three-dimensional location of drill hole or geologic features.

GLOSSARY

ACCELEROMETER—A geophone whose output is proportional to acceleration. A moving coil geophone, for example, with a response proportional to frequency (as may be the case below the natural frequency) may operate as an accelerometer.

ACCOUSTIC LOGGING—A borehole logging survey which will display any of several aspects of acoustic-wave propagation, i.e., a sonic, amplitude, character or 3-D log.

AIR WAVE—Energy from the shot which travels in the air at the velocity of sound: 1050 (1 + 0.00217*T*) ft/sec, where *T* = Fahrenheit temperature, or 331.3 (1 + 0.00366*C*) m/sec, where *C* = Centigrade temperature.

AMPLITUDE—The size of a signal, either in the ground or after amplification. Usually measured from the zero or rest position to a maximum excursion. The amplitude of a signal has units based on the measurement of the signal, i.e., acceleration (in/sec^2), velocity (in/sec) or displacement (in).

ANALOG—(1) A continuous physical variable (such as voltage or rotation)—which bears a direct linear relationship to another variable (such as earth motion) so that one is proportional to the other. (2) Continuous as opposed to discrete or digital.

ANOMALY—A deviation from uniformity in physical properties, often of exploration interest. For example, a travel time anomaly, Bouger anomaly, free-air anomaly.

APPARENT VELOCITY—(1) The velocity with which a wavefront registers on a line of geophones. (2) The inverse slope of a time-distance curve.

AUTOMATIC GAIN CONTROL (AGC)—A system in which the output amplitude is used for automatic control of the gain of a seismic amplifier, usually individual for each channel, although multi-channel devices are sometimes used.

B

BASEMENT—(1) Complex, generally of igneous and metamorphic rocks, overlain unconformably by sedimentary strata. (2) Crustal layer beneath a sedimentary layer and above the Mohorovicic discontinuity.

BEDROCK—Any solid rock exposed at the surface of the earth or overlain by unconsolidated material.

BIT—A binary digit; either a 1 (one) or 0 (zero).

BLIND ZONE—Hidden layer.

BODY WAVES—The only waves which travel through the interior of a body consisting of P-waves and S-waves.

BYTE—An 8 (eight) bit word.

C

CABLE—The assembly of electrical conductors used to connect the geophone groups to the recording instruments.

CASING—Tubes or pipes used to line drill holes or shotholes to keep them from caving in. Usually made in tenfoot lengths which screw together.

CATHODIC PROTECTION—Electrical corrosion protection for pile foundations, electrical grounding mats, buried pipelines generally requiring soil and rock electrical resistivity measurement.

CHANNEL—(1) A single series of interconnected devices through which geophysical data can flow from sources to recorder. Most seismic systems are 24 channel, allowing the simultaneous recording of energy from 24 groups of geophones. (2) A localized elongated geological feature resulting from present or past drainage or water action; often presents a weathering problem. (3) An allocated portion of the radio-frequency spectrum.

CHANNEL WAVE—An elastic wave propagated in a layer of lower velocity than those on either side of it. Energy is largely prevented from escaping from the channel because of repeated total reflection at the channel boundaries or because rays which tend to escape are bent back toward the channel by the increasing velocity away from it in either direction.

CHARACTER—(1) The recognizable aspect of a seismic event, usually in the waveform, which distinguishes it from other events. Usually a frequency or phasing effect, often not defined precisely and hence dependent upon subjective judgment. (2) A single letter, numeral, or special symbol in a processing system. See also byte, with which it is sometimes used interchangeably.

COMMON DEPTH POINT (CDP)—The situation where the same portion of subsurface produces reflections at different offset distances on several profiles.

COMPRESSIONAL WAVE—An elastic body wave in which particle motion is in the direction of propagation. (Same as P-waves, longitudinal wave, dilatation wave). Irrotational.

CONVERTED WAVE—A wave which is converted from longitudinal to transverse, or vice versa, upon reflection or refraction at oblique incidence from an interface.

CRITICAL ANGLE—Angle of incidence, θ_C for which the refracted ray grazes the surface of contact between two media (of velocities V_1 and V_2):

$$\sin \theta_C = V_1 / V_2$$

CRITICAL DISTANCE—Used in either of two different meanings: (1) The offset at which a refracted event becomes the first break; cross-over distance. See Dobrin, p. 73. (2) The offset at which the reflection time equals the refraction time; that is, the offset for which the reflection occurs at the critical angle.

CROSSFEED (Crosstalk)—Interference resulting from the unintentional pickup of information or noise on one channel from another.

CROSS-SECTION—A plot of seismic events.

D

DATUM—(1) The arbitrary reference level to which measurements are corrected. (2) The surface from which seismic reflection times or depths are measured, corrections having been made for local topographic and/or weathering variations. (3) The reference level for elevation measurements, often sea level.

DELAY TIME—(1) In refraction work, the additional time taken for a wave to follow a trajectory to and along a buried marker over that which would have been taken to follow the same marker considered hypothetically to be at the ground surface or at a reference level. Normally, delay time exists separately under a source and under a detector; and is dependent upon the depth of the marker at wave incidence and emergence points. Shot delay time plus geophone delay time equals intercept time. See Dobrin, p. 83. (2) Delay produced by a filter. (3) Time lag introduced by a delay cap such as Elcord.

DIFFRACTION—(1) Scattered energy which emanates from an abrupt irregularity of rock type, particularly common where faults cut reflecting interfaces. The diffracted energy shows greater curvature than a reflection (except in certain cases where there are buried foci), although not necessarily as much as the curve of maximum convexity. It frequently blends with a reflection and obscures the fault location or becomes confused with dip. See Dix, p. 231. (2) Interference produced by scattering at edges. (3) The phenomenon by which energy is transmitted laterally along a wave crest. When a portion of a wave train is interrupted by a barrier, diffraction allows waves to propagate into the region of the barrier's geometric shadow.

DIGITAL—Representation of quantities in discrete units. An analog system is one in which the information is represented as a continuous flow of the quantity constituting the signal.

DIPOLE—A pair of closely spaced current electrodes which approximates a dipole field from a distant pair of voltage detecting electrodes.

E

ELASTIC CONSTANTS:

(1) Bulk modulus, k—The stress-strain ratio under simply hydrostatic pressure:

$$k = \frac{\Delta P}{\Delta V/V}$$

where ΔP = pressure change, V = volume, and ΔV = change in volume, Δ = change of any product.

(2) Shear modulus = rigidity modulus = Lame's constant, μ—The stress-strain ratio for simple shear:

$$\mu = \frac{F_t/A}{\Delta L/L}$$

where F_t = tangential force, A = cross-sectional area, L = distance between shear planes, and ΔL = shear displacement. The shear modulus can also be expressed in terms of other moduli as:

$$\mu = E/(1 + \sigma)$$

where E = Young's modulus, and σ = Poisson's ratio.

(3) Young's modulus = stretch modulus, E—The stress-strain ratio when a rod is pulled or compressed:

$$E = \frac{\Delta F/A}{\Delta L/L}$$

where $\Delta F/A$ = stress (force per unit area), L = original length, and ΔL = change in length.

(4) Lame' λ constant—If a tube is stretched in the up-direction by a tensile stress, S, giving an upward strain, s, and S' is the lateral tensile stress needed to prevent lateral contraction, then:

$$\lambda = S'/s$$

This constant can also be expressed in terms of Young's modulus, E, and Poisson's ratio:

$$\lambda = \frac{\sigma E}{(1 + \sigma)(1 - 2\sigma)}$$

See also Dobrin, pp. 16-18, or Dix, pp. 282-305.

ELECTROMAGNETIC—Periodically varying electromagnetic field, such as light, radio waves, radar.

END LINE—Shotpoints that are shot near the end of the spread.

F

FAN SHOOTING—An early use of the refraction seismograph to indicate the presence of salt domes (within a thick low-velocity section), with detectors located in (widely spaced) fan-like arrays radiating from the shot locations.

FILTER—(1) The part of a system which discriminates against some of the information entering it. The discrimination is usually on the basis of frequency, although other bases such as wavelength or moveout (see velocity filter) may be used. The act of filtering is called convolution. (2) Filters may be characterized by their impulse response or more usually by their amplitude and phase response as a function of frequency. (3) Bandpass filters are often specified by listing successively their low-cut and high-cut component filters. (4) Notch filters reject sharply at a particular frequency. Primarily used to reject 60H line noise. (5) Digital filters provide a means of filtering data numerically in the time domain by summing weighted samples at a series of successive time increments. Digital filtering can be the exact equivalent of electrical filtering. Digital filtering is very versatile and permits one to filter easily in accordance with arbitrarily chosen characteristics which might prove very difficult or impossible to introduce with electrical components.

FIRST BREAK—First arrival—The first recorded signal attributable to seismic wave travel from a known source. First breaks on reflection records are used for information about the weathering. Refraction work is based principally on the first breaks, although secondary (later) refraction arrivals are also used.

FREQUENCY—The repetition rate of a periodic waveform measured in cycles per second or Hertz. Angular frequency measured in radians per second.

G

GALVANOMETER—A part of a seismic camera consisting of a coil suspended in a constant magnetic field. The coil rotates through an angle proportional to the electrical current flowing through the coil. A small mirror on the coil reflects a light beam, which exhibits a visual record of the galvanometer rotation.

GEOPHONE—(SEISMOMETER, JUG) Instrument used to convert seismic energy into electrical energy.

GEOPHONE STATION—Point of location of a geophone on a spread, expressed in engineering notation as 1+75 taken from 0+00 at the beginning of the line.

GRAVIMETER – gravity meter—An instrument for measuring variations in gravitational attraction.

GRAVITY SURVEY—A survey performed to measure the gravitational field, or derivatives, to associate differences in the field with density distribution and therefore differences in rock types.

GROUP VELOCITY—The velocity with which most of the energy in a wave train travels. In dispersive media where velocity varies with frequency, the wave train changes shape as it progresses so that individual wave crests appear to travel at a different velocity (the phase velocity) than the overall energy as approximately enclosed by the envelope of the wave train. The velocity of the envelope is the group velocity. Same as dispersion.

H

HEAD WAVE—The wave which gives a refraction first break. See refraction wave.

HIDDEN LAYER—A layer which cannot be detected by refraction methods, typically a low velocity layer lying beneath a high velocity layer.

HYDRODYNAMIC WAVE—A seismic surface wave propogated along a free surface. The particle motion is elliptical and prograde (M_2 type Rayleigh or Sezawa), i.e., Rayleigh-type wave dependent upon layering.

HYDROPHONE - Pressure detector—A detector sensitive to variations in pressure, as opposed to a geophone which is sensitive to motion. Used when the detector can be placed below a few feet of water—as in marine or marsh work or as a well seismometer. The frequency response of the hydrophone plant depends on its depth beneath the surface because of a standing wave pattern subject to the boundary condition that pressure be zero at the surface and a maximum at a quarter wave length.

I

IN-LINE OFFSET—Shotpoints that are in line, but offset to, a spread.

L

LEADS—An electrical conductor used to connect electrical devices. Geophones are connected to cables at the takeouts via leads on the geophones.

LINE—A series of profiles shot in line.

LOVE WAVE—A surface seismic wave associated with layering. This wave is characterized by horizontal motion perpendicular to the direction of propagation, with no vertical motion.

LOW-VELOCITY LAYER (LVL)—weathering. The surface layer which exhibits low seismic velocity.

M

MAGNETIC SURVEY—A Survey performed to measure the magnetic field, or its components as a means of locating concentrations of magnetic materials or determining depth to basement.

MIS-TIE—(1) The time difference obtained on carrying a reflection event or some other measured quantity around a loop; or the difference of the values at identical points on intersecting lines or loop. (2) In refraction shooting, the time difference from reversed profiles which gives erroneous depth and dip calculations.

MULTIPLE—Seismic energy which has been reflected more than once. Long-path multiple, short-path multiple, peg-leg multiple and ghosts are examples of multiples.

N

NOISE—(1) Any undesired signal; a disturbance which does not represent any part of a message from a specified source. (2) Sometimes restricted to energy which is random. (3) Seismic energy which is not resolvable as reflections. In this sense noise includes microseisms, shot-generated noise, tape-modulation noise, harmonic distortions. Sometimes divided into coherent noise (including non-reflection coherent events) and random noise (including wind noise, instrument noise, and all other energy which is non-coherent). To the extent that noise is random, it can be attenuated by a factor of $\sqrt{n}$ by compositing n signals from independent measurements. (4) Sometimes restricted to seismic energy not derived from the shot explosion. (5) Disturbances in observed data due to more or less random inhomogeneities in surface and near-surface material.

NOISE ANALYSIS—A profile or set of profiles used to gather data for an analysis of coherent noise. Used to design geophone arrays in reflection surveys.

NOISE SURVEY—or ground noise survey. A mapping of ambient, continuous seismic noise levels within a given frequency band. As some geothermal reservoirs are a source of short-period seismic energy, this technique is a useful tool for detecting such reservoirs.

O

OBSERVER—The geophysicist in charge of recording and overall field operations on a seismic crew.

ON-LINE—Shotpoints that are not at any point on a spread other than at the ends of the spread.

ORIGINAL DATA—Any element of data generated directly in the field in the investigation of a site; or a new element of data resulting from a direct manipulation or compilation of the field data.

OSCILLOGRAPH—A device that records oscillations as a continuous graph of corresponding variation in an electric current.

OSCILLOSCOPE—A type of oscillograph that visually displays an electrical wave on a fluorescent screen, as of the cathode ray tube type.

P

PHASE VELOCITY—The velocity with which any given phase (such as a trough or a wave of single frequency) travels; may differ from group velocity because of dispersion.

PLANT—The manner in which a geophone is placed on or in the earth; the coupling to the ground.

PRIMACORD—An explosive rope that can be used to either connect explosive charges, or can be detonated separately as a primary energy source.

PROFILE—The series of measurements made from several shotpoints into a recording spread, from which a seismic data cross section or profile can be constructed.

PVC—Polyvinylchloride, a plastic tubing or pipe that is used to case corings or shotholes.

R

RADAR—A system in which short electromagnetic waves are transmitted into a medium, and the energy which is scattered back by reflecting objects is detected. May be used for shallow penetration surveys in the ground, salt or ice.

RAYLEIGH WAVE—A seismic wave propogated along a free surface. The particle motion is elliptical and retrograde.

RAYPATH—A line everywhere perpendicular to wavefronts (in isotropic media). The path which a seismic wave takes.

RECONNAISSANCE—(1) A general examination of a region to determine its main features, usually preliminary to a more detailed survey. (2) A survey whose objective is to ascertain regional geological structures or to determine whether economically prospective features exist, rather than to map an individual structure.

REFLECTION SURVEY—A survey map of geologic structure using measurements made of arrival time of events attributed to seismic waves which have been reflected from interfaces where the acoustic impedance changes.

REFRACTION SURVEY—A survey to map geologic structure and to determine compressional wave velocities by using head waves. Head waves involve energy which enters a high-velocity medium (refractor).

REFRACTION WAVE - Head wave - Mintrop wave - conical wave—Wave travel from a point source obliquely downward to and along a relatively high velocity formation or marker and thence obliquely upward. Snell's law is obeyed throughout the trajectory. Angles of incidence and of emergence at the marker are critical angles. Typically, refracted waves following successively deeper markers appear as first arrivals with increasing range (shot to detector distance). Refracted waves following different markers may occur at different arrival times for any given range. Such waves cannot arise for angles of incidence less than the critical angle for any given marker. At the critical angle, the refracted wave path (and its travel time) coincides with that of a wide angle reflection.

REFRACTOR - Refraction marker - A relatively high velocity extensive layer, underlying lower velocity layers, which transmits a refraction wave nearly horizontally.

RESISTIVITY (electrical)—A property of rock material giving a measure of the difficulty involved in driving an electrical current through it. Mathematically, resistivity is the ratio of electric field intensity to current density.

RESISTIVITY METER—A general term for an instrument used to measure in situ the resistivity of soil and rock materials.

RESISTIVITY SURVEY—A survey performed to observe the electric fields and earth resistivity caused by introducing a current into the ground.

REVERSE PROFILE—A refraction seismic profile that has been generated by shooting at both ends of a spread.

ROLL-ALONG—A mechanical or electrical switch which permits the connecting of different geophones (or geophone groups) to the recording instruments. The use of a roll-along switch permits common depth point reflection data to be easily acquired in the field.

S

SEISMIC AMPLIFIER—An electronic device used to increase the electrical amplitude of a seismic signal. (See geophone)

SEISMIC CAMERA—A recording oscillograph used to produce a visible pattern of electrical signals to make a seismic record.

SEISMIC CAP—A small explosive designed to be detonated by an electrical current, which in turn detonates another explosive. These caps are designed to provide very accurate time control on the shot instant.

(SEISMIC) VELOCITY—The rate of propagation of seismic wave through a medium.

SEISMOGRAM—A seismic record.

SELF POTENTIAL—Spontaneous potential, natural potential, SP. The dc or slowly varying natural ground voltage between nearby, non-polarizing electrodes.

SHEAR WAVE—A body wave in which the particle motion is perpendicular to the direction of propagation. (Same as S-wave, equivoluminal, transverse wave).

SHOOTER—The qualified, licensed individual (powderman) in charge of all shotpoint operations and explosives handling on a seismic crew.

SHOT DEPTH—The distance down the hole from the surface to the explosive charge. With small charges the shot depth is measured tc the center or bottom of the charge, but with large charges the distances to both the top and bottom of the column of explosives are usually given.

SHOT INSTANT (TIME BREAK, TB, ZERO TIME)—The instant at which a shot is detonated.

SHOTPOINT—Point of location of the energy source used in generating a particular seismogram. Expressed either sequentially for a line (i.e., SP-3) or in engineering notation (i.e., SP 3+00).

SIGNAL ENHANCEMENT—A hardware development utilized in seismographs and resistivity systems to improve signal-to-noise ratio by real-time adding (stacking) successive waveforms from the same source point and thereby discriminating against random noise.

SITE DATA PACKAGE—Accumulation of geophysical data information from a single source of dissemination analysis and evaluation against the site criteria. Would include: charts, records, field notes, maps, photographs, technical reports, lab reports.

SNELL'S LAW—When a wave crosses a boundary between two isotropic mediums, the wave changes direction such that the sine of the angle of incidence of the wave divided by the velocity of the wave in the first medium equals the sine of the angle of refraction of the wave in the second medium divided by the velocity of the wave in the second medium (see critical angle).

SPREAD—The layout of geophone groups from which data from a single shot are recorded simultaneously.

STONELEY WAVE—A type of seismic surface wave propagated along an interface.

SURFACE WAVE—Energy which travels along or near the surface (ground roll).

T

TAKEOUT—The connections on a multiconductor geophone cable which allow the geophones to be attached. In some cases also refers to the short cable leads exiting from the geophones (pigtails).

TIME BREAK—The mark on a seismic record which indicates the shot instant or the time at which the seismic wave was generated.

TRACE—A record of one seismic channel. This channel may contain one or more geophones. A trace is made by a galvanometer.

V

VIBRATION MONITOR—A sensitive, calibrated recorder of ground and structural acceleration and velocity. Measurements are made to determine vibrational amplitudes and modal frequencies of buildings, towers, etc., under ambient conditions, as well as potentially damaging vibrations due to blasting, pile driving.

VIBROSEIS*—A seismic energy source consisting of controlled frequency input into the earth by way of large vibrators (truck mounted).

W

WAVE LENGTH—The distance between successive similar points on two adjacent cycles of a wave, measured perpendicular to the wavefront. Expressed as $\lambda = v/f$, where λ = wavelength, v = wave velocity and f = wave frequency.

WAVE TRAIN—(1) The sum of a series of propagating wave fronts emanating from a single source. (2) The complex wave form observed in a seismogram obtained from an explosive source.

WEATHERING SPREAD —A short spaced geophone interval, refraction spread used to provide corrections to refraction data, due to delay times in near-surface, low velocity materials.

WWV—The U.S. Bureau of Standards radio station that broadcasts time and frequency standards.

* * * * *

---

* Trademark of Continental Oil Company (Conoco).

For the definition of other geophysical terms used in this manual, refer to: *Glossary of Terms Used in Geophysical Exploration,* Society of Exploration Geophysicists, Tulsa, Oklahoma, 1984.

BIBLIOGRAPHY

GENERAL GEOPHYSICS

Arandelovic, D., *Geophysics in Civil Engineering,*Tisak, Zagreb, Yugoslavia, 1969.

Clark, Sydney, P., *Handbook of Physical Constants,* Geological Society of America, N.Y., NY, 1966.

Dobrin, Milton B., *Introduction to Geophysical Prospecting,* McGraw-Hill, New York, NY, 1960.

Griffiths, D.H., and King, R.F., *Applied Geophysics for Engineers and Geologists,* Pergamon Press, N.Y., NY, 1965.

Heiland, C.A., Geophysical Exploration: Hafner, N.Y., NY, 1968.

Jakosky, J.J., *Exploration Geophysics,* Trija Publishing Company, Los Angeles, CA, 1950.

Parasnis, D.S., *Mining Geophysics,* Elsevier Scientific Publishing Company, N.Y., NY, 1975.

Telford, W.M., Geldhart, L.P., Sheriff, R.E., and Keys, D.A. *Applied Geophysics*, Cambridge University Press, London and N.Y, NY, 1976.

SEISMIC

Bollinger, G.A., *Blast Vibration Analysis*, Southern Illinois University Press, Carbondale, IL, 1971.

Dix, C. Hewitt, *Seismic Prospecting for Oil*, Harper & Bros., New York, NY, 1952.

Ewing, W. Maurice, Jardetsky, W.S., and Press, Frank, *Elastic Waves in Layered Media*, McGraw-Hill, New York, NY, 1957.

Kitsunezaki, C., In Situ Determination of Variation of Poisson's Ratio in Granite Accompanied by Weathering Effects and Its Significance in Engineering Projects, 1965.

_____________, *Field Experimental Study of Shear Waves and Related Problems*, Contributions of the Geophysical Institute, Kyoto University, Japan, 1971.

Leet, L. Don, *Earth Waves*, John Wiley & Sons, New York, NY, 1950.

_____________, Vibrations from Construction Blasting: Hercules Powder Company, Wilmington, DE, 1969.

_____________, Effects Produced by Blasting Rock: Hercules Powder Company, Wilmington, DE, 1971.

Mossman, R.W., and Heim, G.E., *Seismic Exploration Applied to Underground Excavation Problems*, Vol. I, Proceedings of the North American Rapid Excavation and Tunneling Conference, Chicago, IL, American Society of Civil Engineers, 1972.

Musgrave, Albert W. (ed), *Seismic Refraction Prospecting*, Society of Exploration Geophysicists, Tulsa, OK, 1967.

Nichols, Harry R., Johnson, Charles F., and Duvann, Wilbur I., Blasting Vibrations and Their Effects on Structures:

Department of the Interior, Bureau of Mines Bulletin 656, Washington, D.C., 1971.

Slotnick, Morris Miller, *Lessons in Seismic Computing*, Society of Exploration Geophysicists, Tulsa, OK, 1959.

Soske, Joshua L., The Blind Zone Problem in Engineering Geophysics: *Geophysics*, Vol. 24, pp. 359-365, 1958.

Tucker, Paul M. and Yorston, Howard J., Pitfalls in Seismic Interpretation: Society of Exploration Geophysicists, J. C. Hollister (ed.), Monograph No. 2, 1973.

White, J.E., Motion Product Seismograms: *Geophysics*, Vol. 29, pp. 288-298, 1964.

____________, *Seismic Waves—Radiation, Transmission and Attenuation*, McGraw-Hill, New York, NY, 1965.

____________, *In Situ Measurement of Soil Properties*, Volumes I & II, American Society of Civil Engineers, 345 East 47th Street, N.Y., NY 10017, 1975.

RESISTIVITY

Iu. V. Lakubovskii, V., and Liajov, L., Exploration Electrica, Editorial Reverte, S.A., Madrid, Spain (in Spanish), 1980.

Kunetz, Geza, *Principles of Direct Current Resistivity Prospecting*, R. van Nostrand Publishers, VA, 1966.

Mooney, Harold M., and Wetzedl, W.W., 1965, *The Potentials About a Point Electrode and Apparent Resistivity Curves for a Two-, Three-, and Four-Layered Earth*, University of Minnesota Press, Minneapolis, MN, 1965.

Orellana, Ernesto, and Mooney, Harold M., Master Tables and Curves for Vertical Electrical Sounding Over Layered Structures: Interciencia, Madrid, Spain,1966.

____________, Prospeccion Geoelectrica, Paranaifo, Madrid, Spain. (Two Volumes—in Spanish), 1974.

Roman, Irwin, Apparent Resistivity of a Single Uniform Overburden: United Stages Geological Survey Professional Paper 365, U.S. Government Printing Office, Washington, D.C., 1960.

Tagg, C.F., *Earth Resistances*, Pitman Publishing Company, New York, NY, 1964.

Van Nostrand, Robert G., and Cook, Kenneth L., Interpretation of Resistivity Data: United States Geological Survey Professional Paper 499, U.S. Government Printing Office, Washington, D.C., 1966.

ELECTROMAGNETIC

Keller, G., Frischknect, F., Electrical Methods in Geophysical Prospecting, Pergamon Press, N.Y., NY, 1966.

McNeill, J., Technical Notes, Geonics Limited, Ontario, Canada, 1980 to present.

Morley, L.W., (ed.), *Mining and Groundwater Geophysics*, Geological Survey of Canada, Econ. Geol. Dept. No. 26, 1967.

Wait, J.R., (ed.), *Electromagnetic Probing in Geophysics*, The Golem Press, Boulder, CO, 1971.

GROUND PROBING RADAR

Benson, R., and Glaccum, R., The Application of Ground Penetrating Radar to Soil Surveying. National Aeronautical and Space Administration (NASA), Cape Canaveral, FL, 1979.

_____________, Remote Assessment of Pollutants in Soil and Groundwater. In *Proceedings of the Hazardous Material Risk Assessment, Disposal and Management Conference*, Miami Beach, FL, 1979.

_____________, Radar Surveys for Geotechnical Site Assessment. In *Geophysical Methods in Geotechnical Engineering*, American Society of Civil Engineers, Atlanta, GA., p. 161, 1979.

Fountain, L., Herzig, F., and Owens, T., Reflection of Subsurface Cavities by Surface Remote Sensing Techniques, FHA Report No. FHWA-RD-7580, Office of Research and Development, Washington, D.C., 1975.

Morey, R., Annan, P., Davis, J., and Rossiter, Jr., Impulse Radar—Principles and Applications, Course Notes—Volumes I and II. Center for Cold Ocean Resources Engineering, Memorial University of Newfoundland, St. Johns, Newfoundland, 1978.

SELF POTENTIAL

Alfano, L., Geoelectrical Prospecting with Underground Electrodes, *Geophysical Prospecting*, Vol. 10, No. 3, pp. 290-303, 1962.

Ball, B., and Fuerstenau, D.W., A Review of the Measurement of Streaming Potentials: *Miner Sci. Engng.*, Vol. 5, No. 4, pp. 267-277, 1973.

Bhattacharya, B.B., and Roy, N., A Note on the Use of a Nomogram for Self-Potential Anomalies; *Geophysical Prospecting*, Vol. 29, pp. 102-107, 1981.

Bogoslovsky, V.A., and Ogilvy, A.A., Natural Potential Anomalies as a Quantitative Index of the Rate of Seepage from Water Reservoirs, *Geophysical Prospecting*, Vol. 18, pp. 261-268, 1969.

____________, Application of Geophysical Methods for Studying the Technical Status of Earth Dams, *Geophysical Prospecting*, Vol. 18, pp. 758-773, 1970.

Corwin, R.F., and Hoover, D.B., The Self-Potential Method in Geothermal Exploration, *Geophysics*, Vol. 44, No. 2, pp. 226-245, 1979.

Corwin, R., The Self-Potential Method and Its Engineering Applications, Paper presented at Annual SEG Meeting, Atlanta, GA, 1984.

Davenport, G.C., Hadley, L.M., and Randall, J.A., The Use of Seismic Refraction and Self-Potential Surveys to Evaluate Existing Embankments: Paper presented at Rocky Mt. regional AIME meeting, Vail, CO, Aug. 3-5, 1983.

Meiser, P., A Method for Quantitative Interpretation of Self-Potential Measurements, *Geophysical Prospecting*, Vol. 10, No. 2, pp. 203-218, 1962.

Ogilvy, A.A., Ayed, M.A., and Bogoslovsky, V.A., Geophysical Studies of Water Leakages from Reservoirs, *Geophysical Prospecting*, Vol. 17, No. 1 (March 1969), pp. 36-62, 1969.

Ogilvy, A.A., and Bogoslovsky, V.A., The Possibilities of Geophysical Methods Applied for Investigating the Impact of Man on the Geological Medium, *Geophysical Prospecting*, Vol. 27, pp. 775-789, 1979.

Roy, A., and Chowdhury, D.K., Interpretation of Self-Potential Data for Tabular Bodies, *Journal of Science and Engineering Research*, Vol. III, Part I, pp. 35-45, 1959.

Sato, M., and Mooney, H.M., The Electrochemical Mechanism of Sulfide Self-Potentials: *Geophysics*, Vol. 25, No. 1, pp. 226-249, 1960.

Wynn, J.C., and Sherwood, S.I., The Self-Potential (SP) Method: An Inexpensive Reconnaissance and Archaeological Mapping Tool: in press, 1983.

MAGNETICS

Breiner, S., Applications Manual for Portable Magnetometers, Geometrics, Sunnyvale, CA, 1973.

Chapman, J., and Bentels, J., *Geomagnetism*, Vols. I and II, Oxford University Press, London, 1940.

Hasbrouck, W., Techniques of High Spatial Density Magnetic Profiling and Mapping, NOAA Technical Report ERL 201-ESL 15, Boulder, CO, 1970.

Nagata, T., Rock Magnetism, Maruzen, Tokyo, Japan, 1961.

Nettleton, L.L., Elementary Gravity and Magnetics for Geologists and Seismologists: Society of Exploration Geophysicists Monograph No. 1, 1971.

GRAVITY

Grant, F.S., and West, G.I., *Interpretation Theory in Applied Geophysics*, McGraw-Hill, N.Y., NY, 1965.

Nettleton, L.L., *Geophysical Prospecting for Oil*, McGraw-Hill, New York, 442 p., 1940.

____________, Gravity and Magnetic Calculation: *Geophysics*, Vol. 7, 1942.

Parasnis, D.S., *Principles of Applied Geophysics*, John Wiley & Sons, N.Y., NY, 1962.

PERIODICALS

Geophysics, published six times a year by the Society of Exploration Geophysics, P.O. Box 3098, Tulsa, Okla. 74101. Comes with membership in the Society, which costs $18 annually. Devoted mainly to geophysics in petroleum exploration, but occasionally has good articles on engineering.

Geophysical Prospecting, published four times a year by the European Association of Exploration Geophysicists, P.O. Box 162, The Hague, Netherlands. Comes with membership in the Society, which costs $22 annually. Very practical applied geophysics to both engineering and exploration.

Chapter 14
BOREHOLE GEOPHYSICAL AND WIRELINE SURVEYS

Introduction

Wireline surveys determine physical properties in and beyond the wall of a borehole by passing through the borehole detection devices attached to a cable, or wireline. Subsurface geologic conditions and engineering characteristics can be derived directly or indirectly from the wide variety of measured properties available to wireline surveying. Wireline logging techniques commonly are classified by the kind of energy that is input (active systems) and/or received (passive systems), including electrical, seismic or acoustic, nuclear radiation, magnetic field, gravity, or light (optical). Data from several systems often are combined to derive a single geologic or engineering characteristic. The use of wireline surveys permits the gathering of a larger volume of data from a borehole or group of boreholes than can be achieved by direct physical sampling alone and makes possible the logging of old boreholes and wells. This chapter describes the systems and discusses the application of borehole wireline surveying methods to engineering geology exploration and investigation.

Electrical Logging Techniques

An electrical log is a continuous record of the electrical properties of the fluids and geologic materials in and around a borehole. Electrical logging is performed in the uncased portion of a borehole by passing electrical current into the lowering cable, through electrodes located in the logging device, or sonde, and out into the borehole and the geologic medium. Other electrodes located on the surface or in the borehole complete the circuit and return the current to the source and recording device. Electrical logging surveys are efficient and cost effective because the systems are automated and rapid and because several electrical property measurements or electrode configurations are often provided in the same exploration tool allowing simultaneous readings.

Applications

Electrical logging techniques can be used in geotechnical investigations to obtain data on the variation with depth of geologic materials and associated fluids. Electrical logs from two or more boreholes provide a means of correlating and determining the continuity of geologic strata or zones that have similar electrical properties. Since the electrical properties are dependent on strata physical characteristics, the porosity, mineral composition, water content (saturation), water salinity, and the lithology of the strata can often be deduced. Borehole electrical logs are also the best source of control for surface geoelectrical surveys by providing values of subsurface layer resistivities. Electrical log correlation of continuous strata from borehole to borehole is relatively simple. The interpretation of physical properties from electrical logs can be ambiguous and complicated. For example, different combinations of water content, salinity, mineralogy, porosity, and borehole peculiarities can produce similar electrical log reactions. Some references to aid in interpretation of electrical logs are Schlumberger [1], Keller and Frischknecht [2], O.C.E. [3], Tixier [4], Pickett [5], and Scientific Software Corporation [6].

Equipment Requirements

Logging devices, vehicles, manpower and power supply requirements vary depending on the type of survey, the manufacturer's design or the service company's operational methods, and the portability or size of the survey device. Most electrical logging systems are truck mounted, some are truck mounted but portable (may be removed from the truck) and a few are now back-pack portable by one person. Many systems are capable of performing auxiliary surveys such as gamma ray, temperature and caliper in addition to the primary electrical logging functions. All systems require an armored conductor cable, a logging sonde (the in-hole logging device), a winch for lowering and raising the sonde, an electrical power supply, and a recording device.

Operational Costs

Well logging services that supply the equipment and operators and furnish the completed log for a set fee are available nationwide. Costs of owning and operating electrical well logging systems consist of the initial cost of the system and accessories, repair and maintenance of equipment, purchase of supplies, and personnel (in terms of training, and time to conduct survey and interpret results). System costs vary greatly from large truck mounted systems to compact backpack-portable systems. Crew sizes vary from one to two persons. Actual logging time for a typical geotechnical boring of one to several hundred feet deep is only a matter of minutes with logging rates as high as 100 ft/min (0.5 m/sec). The entire operation of setting up and demobilizing can be completed in a matter of hours, even for several boreholes. The time required for well log interpretation varies with the type of logs obtained, the complexity of the subsurface geology and hydrology, the parameters desired, and the experience of the interpreter. Logging service companies do not commonly provide data interpretation. Exploration costs can be reduced substantially by logging existing wells or boreholes and by obtaining existing well logs of boreholes at or near the site. Many state geologic surveys an other agencies conduct well logging and/or maintain well logs and well log catalogs, and should be consulted before the field program is commenced.

Electrical Logging Systems.—Downhole wireline electrical logging systems measure natural potentials produced in the subsurface or the electrical resistance (resistivity) of subsurface materials to a current emitted by the system. The electrical resistivity systems differ in the numbers, position, and spacing of the current and measuring (potential) electrodes used by the systems. Systems vary from single electrode arrays to various multiple electrode configurations designed to measure or detect zones or strata that are intercepted by the borehole. Systems described below are the spontaneous potential; the single-point resistivity array; the multiple down-hole electrode arrays including short-normal, long-normal, lateral and focused logs; the microlog; the induction log; and the fluid resistivity device.

(1) Spontaneous potential (SP).—The spontaneous potential or SP logging device records the difference in potential in millivolts between a fixed electrode at the surface and the electrode in the borehole (fig. 14-1). The measured potential

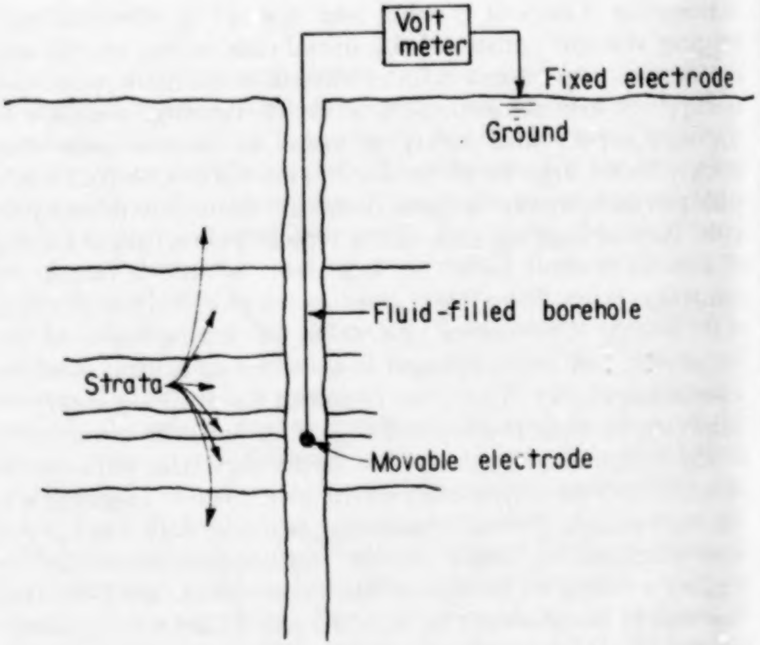


Figure 14-1. – Spontaneous potential survey elements.

difference changes as the electrical potential between the borehole fluid and the fluids in the various strata opposite the sonde changes. The spontaneous potential device commonly is incorporated into the multiple-electrode resistivity sonde so that resistivity and SP logs are acquired simultaneously. The SP log is recorded on the left-hand side of the log sheet opposite the resistivity logs. Figure 14-2 illustrates typical responses of an SP-resistivity log. The recording is a relative measurement of the voltage in the borehole. Readings opposite shales are relatively constant and form the shale baseline, or "shale line," which is usually placed at the right side of the SP log. The SP curve typically deflects to the left or right opposite permeable formations depending on the salinity of the drilling mud. Sandstones and other porous and permeable strata allow the different fluids to mix and produce, salinity of the pore fluid with respect to the borehole fluid, and the clay content of the strata. The SP peaks are commonly displayed to the left of the shale line because negative potentials are more commonly encountered.

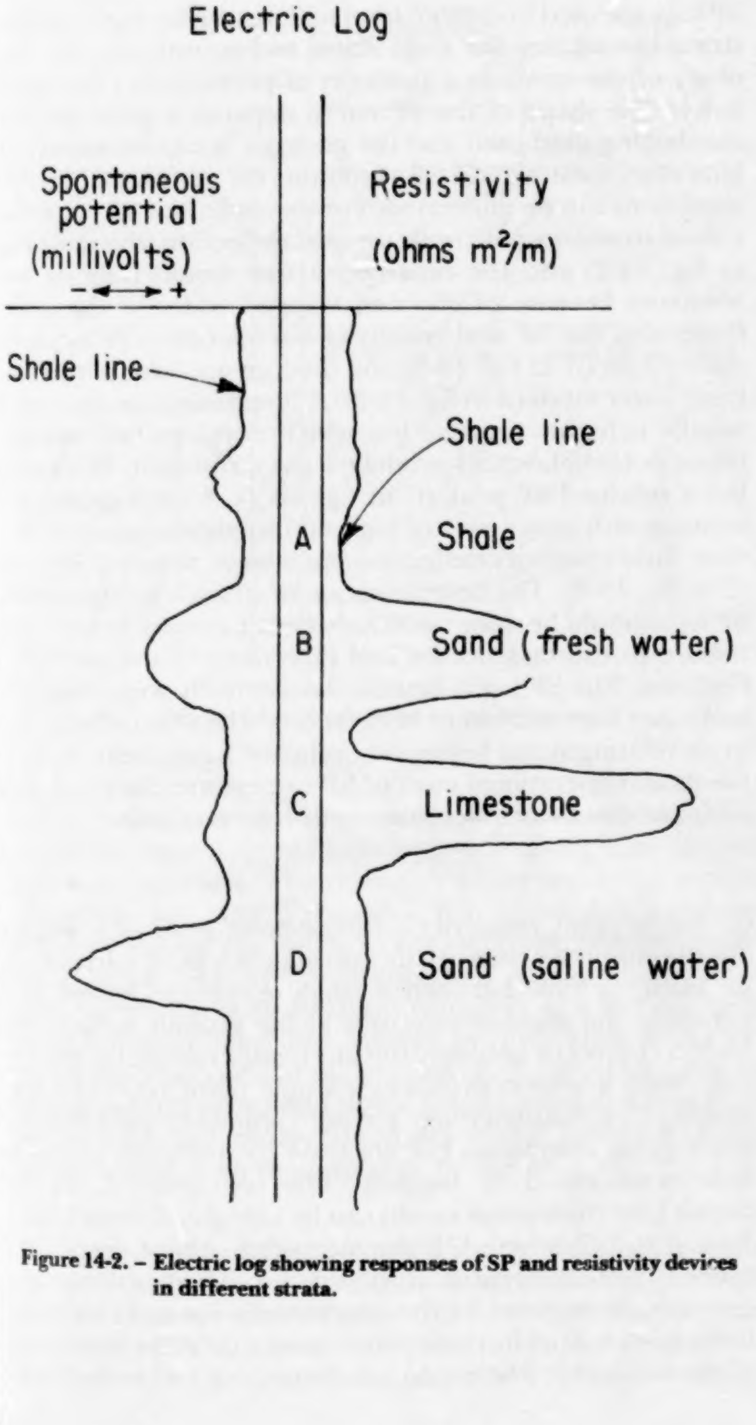


Figure 14-2. – Electric log showing responses of SP and resistivity devices in different strata.

SP logs are used in combination with resistivity logs to define strata boundaries for correlation and to estimate the lithology of the strata as a function of permeability and resistivity. The shape of the SP curve depends a great deal on the drilling mud used and the geologic strata encountered. However, some typical SP responses for various subsurface conditions can be illustrated. For example, the SP curve for a shale stratum would indicate zero deflection (the shale line in fig. 14-2) and the resistivity curve would indicate low resistivity because of clay and trapped water in the shale. Generally, the SP and resistivity curves converge opposite shale strata (A in fig. 14-2) and diverge opposite permeable fresh water sands (B in fig. 14-2). A limestone stratum, which usually is highly resistive but which develops little spontaneous potential, would produce a large resistivity deflection but a subdued SP peak (C in fig. 14-2). A permeable sand stratum with pore water of high salinity typically would produce little resistivity deflection but a large negative SP peak (D in fig. 14-2). The determination of strata lithologies from SP logs should be done cautiously because many factors contribute to the magnitudes and directions of the curve deflections. The SP log is best used collectively with resistivity and other logs as a means of detecting strata boundaries and in correlating strata between boreholes. Equipment requirements and operational costs of SP surveys are discussed with multiple down-hole electrode resistivity methods.

(2) Single-point resistivity.—Single-point resistivity loggers are the simplest resistivity measuring devices. A current can be made to flow between a single electrode placed in a borehole and another electrode at the ground surface (fig. 14-3). The earth between the electrodes completes the circuit. Such a system produces a single point resistivity log. Single-point resistivity logs are not commonly used in modern logging operations but illustrate the principle of downhole earth resistivity logging. The resistance, R, of the circuit (electrodes plus earth) can be calculated from Ohm's Law, $R = V/I$, where V is the measured voltage drop and I is the current generated at the surface. The resistance of a circuit is determined by the conductor's size and shape and its resistivity, ρ, an intrinsic property of a material. Resistivity of the conductor (the earth) is a convenient and useful prop-

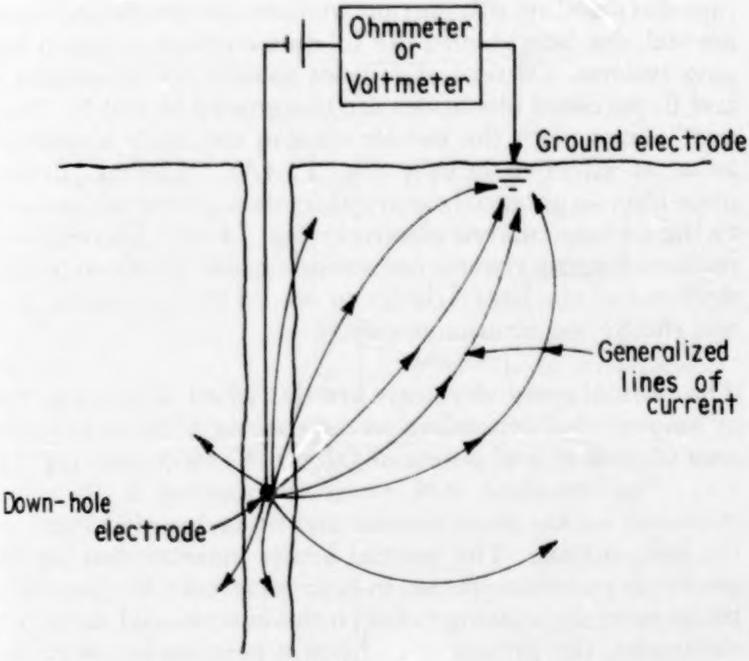


Figure 14-3. – Single-point resistivity array.

erty to measure because it provides information concerning pore fluid content, pore fluid composition, and lithology and continuity of strata. The resistivity of the measured section of earth is determined from $\rho = KR$, where KR is a shape factor which differs for different electrode configurations and R is the measured resistance V/I. A single point resistivity log measures an apparent resistivity of a section made up of borehole fluid and the various individual strata between the borehole and the ground electrode. The multiple electrode arrays discussed below are designed to narrow and better define the measured sections so that individual strata are represented more accurately by the logs.

(3) Multiple electrode arrays.—Wireline electrical systems using multiple down-hole electrode arrays in the borehole provide better resolution of resistivity and associated properties of individual strata within the subsurface than can be achieved with the single-point array. Multiple electrode ar-

rays discussed in this section include the short- and long-normal, the lateral, and the focused-current or guard logging systems. Current electrodes usually are designated A and B; potential electrodes are designated M and N. "Normal" arrays place the in-hole current electrode located far away, at effective infinity (fig. 14-4A). "Lateral" devices place the two potential electrodes close together with respect to the in-hole current electrode (fig. 14-4B). Conventional modern logging systems use a sonde made up of two normal devices and one lateral device to record three resistivity logs and the SP log simultaneously.

The normal resistivity arays are described as short-normal or long-normal depending on the spacing of the in-hole current (A and B) and potential (M and N) electrodes (fig. 14-4A). The standard AM electrode spacing is 16 inches (400mm) for the short normal and 64 inches (1625mm) for the long normal. The normal arrays measure and log the electrical potential at the in-hole electrode M. Generally, the greater the spacing between the current and measuring electrodes, the greater the effective penetration of the device into the surrounding medium.

The lateral resistivity array is shown in figure 14-4B. The actual positions of the electrodes in practice may vary from the circuit shown but the resistivity measurements are the same. The lateral array spacing is measured from the A current electrode to the center (0) of the potential electrode configuration and is called the AO spacing. The lateral array measures the potential difference, or gradient, between the two in-hole potential electrodes and is also called the gradient array. The influence of the geologic medium away from the borehole (the effective penetration of the system) is greatest for the lateral array with its 18 ft 8 in (5690mm) spacing and least for 16 in (400mm) short normal array.

The focused-current, or guard, resistivity device is a modified single-electrode array in which "guard" current electrodes are placed above and below a central current electrode and two pairs of potential electrodes (fig. 14-5). Current in the central and guard electrodes is adjusted so that zero potential exists between the potential electrodes and the current is thus forced or focused to flow out into

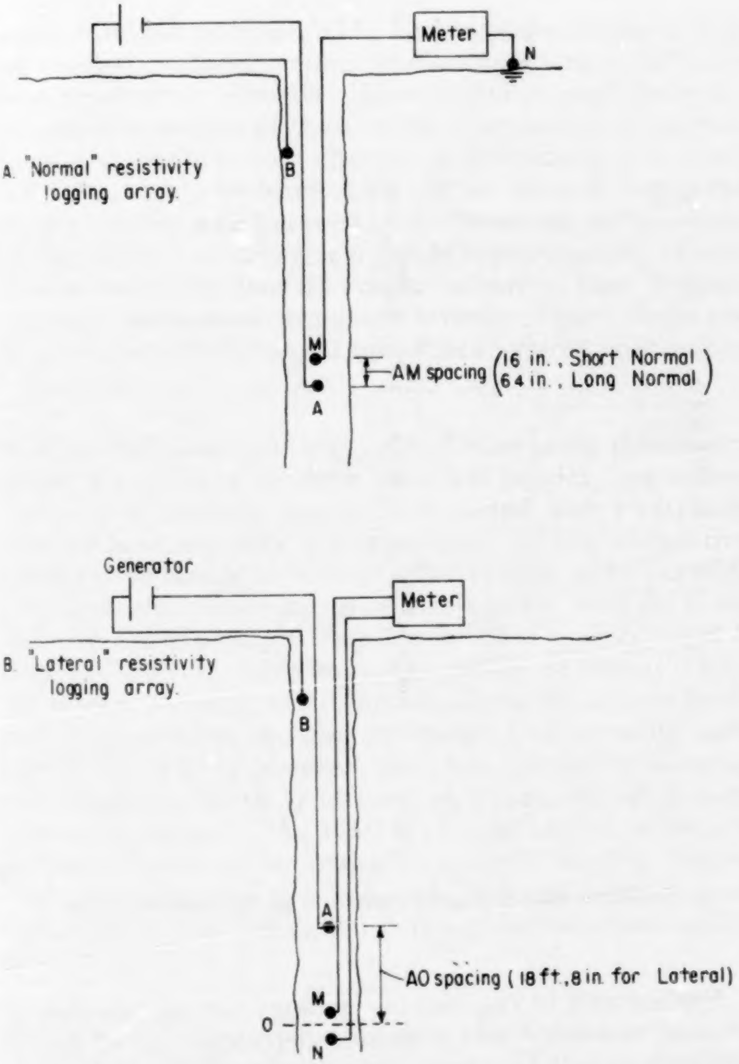

Meter
N
A. "Normal" resistivity logging array.
B
M
A
AM spacing (16 in., Short Normal / 64 in., Long Normal)
Generator
Meter
B. "Lateral" resistivity logging array.
B
A
AO spacing (18 ft., 8 in. for Lateral)
M
O
N

Figure 14-4. – Multiple-electrode resistivity arrays [A, B are current electrodes. M, N are potential electrodes.]

the geologic medium in a narrow band. The device then measures the potential between the sonde electrodes and a reference electrode at the ground surface. Focusing of the current into a band of predetermined thickness gives the focused array much greater thin bed and stratum boundary resolution than the other arrays.

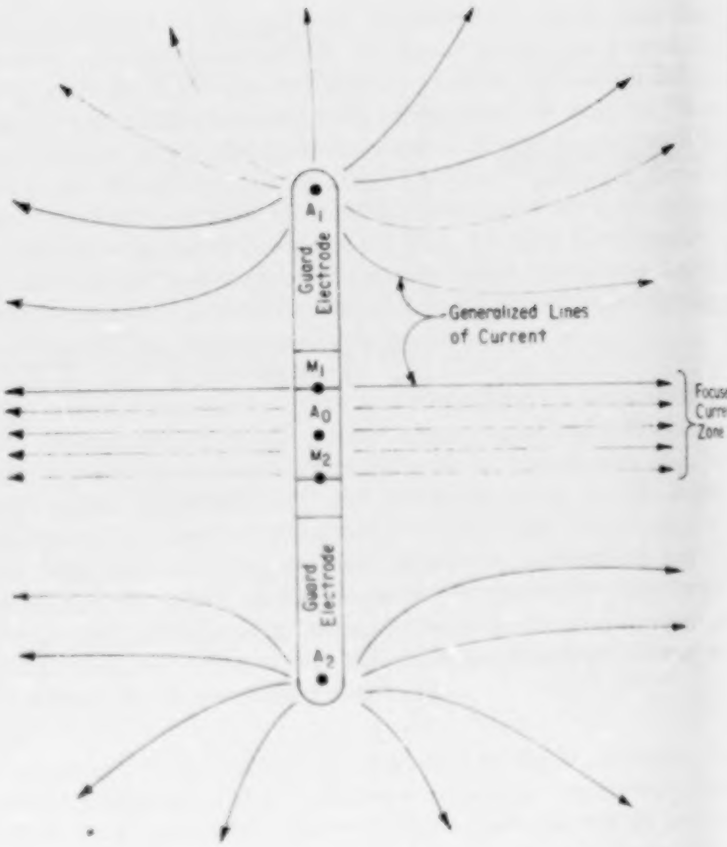


Figure 14-5. – Focused current, or guard, resistivity array.

Applications in engineering geology for the multiple-electrode resistivity arrays include determination of apparent resistivity and an approximation of true resistivities of individual strata or zones. The determination of resistivity aids in the interpretation of surface electrical surveys which generally are less expensive to conduct than downhole surveys and can be applied over large areas of investigation. Since the depth of penetration of the measuring circuit into the geologic medium varies with the electrode spacing, logs of the various arrays (short- and long-normal and lateral) can be analyzed collectively to discriminate the effects of stratum thickness, borehole fluids, the drilling mudcake, and variations in fluids and permeabilities of strata at various distances from the borehole. The shapes of the curves of logs for several boreholes permit correlation of strata and zones from borehole to borehole. Normal devices produce better boundary definition of thick strata than do lateral devices, but lateral logs are more effective in delineating thin strata and thin, highly resistive zones. The focused logs more sharply discriminate between different strata, define strata boundaries better, and give a better approximation of true stratum resistivity than do normal or lateral logs. Porosity and water content of strata and salinity of pore fluids can be calculated with the logs if sufficient accessory information is obtained.

Multiple-electrode resistivity and SP measuring devices are standard systems in modern electrical logging operations. The units commonly are truck mounted with electrically powered lowering devices and nominal 115 volt alternating current (AC) power provided by the vehicle or by portable generators. Maximum depth of investigation with the truck mounted systems varies from about 3000 to over 5000 ft (900 to 1500m), with logging speeds of about 15 to 100 ft/min (0.1 to 0.5 m/sec). Man-portable units in backpack configuration are also available. The portable units typically are battery powered, use a hand winch for lowering and raising the sonde, and have typical maximum investigations depths of 650 to 1150 ft (200 to 350m). Minimum borehole diameters for multiple-electrode logging devices range from one inch to 3-7/8 inch (100mm) depending on the complexity and designed depth of investigation of the sonde.

Crew size, vehicle costs and logging time determine the costs of multiple-electrode resistivity surveys. Logging time can vary from a few minutes to 15 minutes for a 100 ft (30m) borehole, including set up and take down time. Logging generally requires only one person. Commercial well-logging service companies have set fees and should be contacted for job cost estimating.

(4) Microlog.—Special purpose electrical logging devices are available to supplement or in some cases replace standard resistivity logging systems. The microlog (also called contact log, microsurvey, and minilog) records variations in resis-

tivity of a narrow, shallow zone near the borehole wall. The microlog sonde is equipped with three closely spaced electrodes placed on a rubber pad which is pressed against the borehole wall (fig. 14-6). Microlog electrode spacings are about one to two inches. Depth of investigation for the microlog is about 3 inches (75mm) from the borehole wall. Normal, lateral and guard arrays can be configured in the

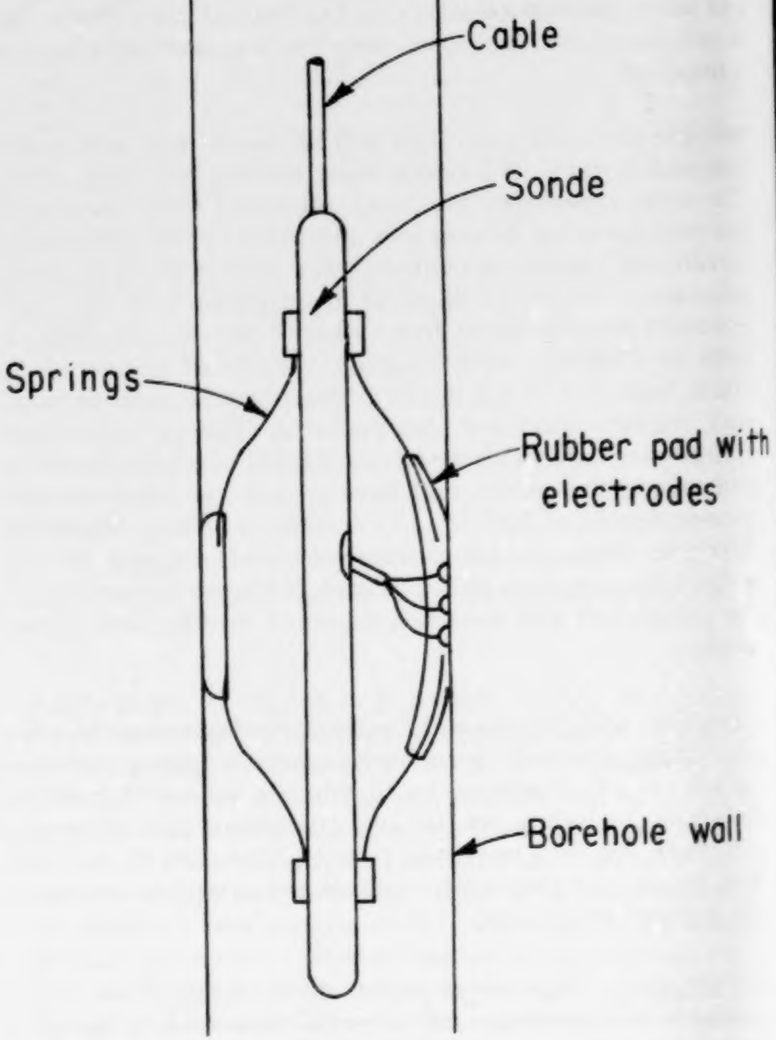


Figure 14-6. – Microlog resistivity logging device.

microlog survey. The microlog can be used to delineate thin resistivities with the mud resistivity. Porous permeable zones allow the mud cake to penetrate the strata and the resulting microlog will indicate resistivities close to that of the mud. Truck-mounted microlog devices requires a boring with a minimum diameter of 4-1/2 inches (115mm).

(5) Induction logging.—The induction logging device permits electrical logging in dry boreholes or boreholes containing non-conducting fluids. The induction logger is housed in a separate sonde that uses an induction coil to excite a current in the geologic medium around a borehole. The induction logger is a focused device and produces good thin stratum resolution at greater distances from the borehole than can be achieved with normal spacing devices. Its primary advantage over other devices is that it does not require a conductive fluid in the borehole. The measured resistivity is recorded on a strip chart recorder as in the standard logging systems. The logging (sonde travel) rate for induction logging is approximately 15 to100 ft/min (0.1 to 0.5 m/sec). Truck-mounted induction loggers require a minimum 3-in (75mm) borehole).

(6) Fluid resistivity device.—Fluid resistivity devices measure the resistivity of the borehole fluid continuously as the sonde is raised. Fluid resistivity logs permit corrections of measurements made with other resistivity systems. They are also useful in hydrological and ground-water recharge into the borehole. The diameter of a typical fluid resistivity sonde is 1-3/8 inch (35mm).

Nuclear Radiation Logging Techniques

A nuclear radiation log is a continuous record of the natural or induced radiation emitted by geologic materials near the borehole. Nuclear radiation logging is performed by raising a sonde containing a radiation detector or a detector and a radioactive source up the borehole and recording changes in electrical impulses produced by radiation bombardment at the detector.

Applications

Nuclear radiation logs can be used in geotechnical investigations to correlate continuity of strata between boreholes, to aid in determination of lithology, and to derive or measure directly many physical parameters of the subsurface materials, including bulk density, porosity, water content, and relative clay content. Most nuclear radiation logging systems can be operated in cased boreholes, giving them an advantage over electrical wireline logging systems. Nuclear logs can also be run in old boreholes, which are more likely to be cased than recent boreholes. Nuclear borehole logging can be used effectively in the fields of foundation engineering and hydrology for depths ranging from 10 to more than 1000 ft (3 to more than 300m). At considerable depths, as for large buried structures, nuclear logging is a cost-effective means of expanding a small number of data points obtained from direct measurements on core samples to continuous records of clay content, bulk density, water content, and porosity. The logs are among the simplest to perform and interpret, but the calibrations required for meaningful quantitative interpretations must be meticulously complete in attention to detail and consideration of all factors affecting nuclear radiation in earth materials. Nuclear radiation logging tools should be calibrated in controlled calibration pits that may require a usage fee [7]. Under favorable conditions, nuclear measurements approach the precision of direct density tests on rock cores. The gamma-gamma density log and the neutron water content log require the use of isotopic sources of nuclear radiation. Potential radiation hazards necessitate thorough training of personnel working around the logging sources. Useful references concerning the application and interpretation of wireline nuclear radiation logs include O.C.E. [3], Picket [5], Schlumberger [1], and Scientific Software Corporation [6].

Equipment requirements

Equipment requirements for nuclear radiation logging systems are similar to those of electrical logging systems: a vehicle equipped with hoist and electrical power, shielded armored cable, and logging sonde and recorder. In addition, most systems require a radioactive source material and the proper shielded container or vault required to transport the source. A back pack—portable logging system capable of performing electrical logging and gamma ray logging (natural gamma radiation measurement) is available.

Operational costs

Operational costs are higher for nuclear radiation logging because logging speeds are generally slower than for electrical logging and because many of the techniques require careful and frequent calibration. Crews must be trained and certified to handle radioactive materials and special provisions must be made in logging vehicles to safeguard radioactive materials. Logging speeds for nuclear radiation devices are generally less than 30 ft/min (0.15 m/sec). Data acquisition (field) time is correspondingly greater for radiation logging.

Nuclear logging systems

Three commonly applied wireline nuclear radiation systems are the gamma ray or natural gamma logger, the gamma-gamma or density logger, and the neutron logger. The gamma-gamma and neutron devices require the use of a radioactive source material; the gamma ray device does not (it is a passive device). All the systems employ an in-hole sonde containing the source and/or detector. Most devices require a borehole diameter of at least 2 inches (50mm) and investigate a zone extending 6 to 12 inches (150 to 300mm) from the borehole. Applications differ for the three systems and depend on the properties measured.

(1) Gamma ray (natural gamma) device.—The gamma ray or natural gamma radiation device provides a continuous record of the amount of natural gamma radiation reaching the detector after having been emitted by geologic materials near the sonde (fig. 14-7). The gamma-ray detector converts incoming gamma radiation to electrical impulses proportional to the number of rays detected and sends the amplified electrical impulses to the surface for plotting on a graphic recorder. Gamma ray logs generally reflect the presences of shale or clay strata in the subsurface because clay minerals commonly contain the potassium isotope K^{40}, which is the primary source of natural gamma radiation in most sediments. Shales and clays usually produce a high gamma ray count, or a peak on the log.

The relative density of a stratum is also indicated by gamma ray logs because gamma radiation is absorbed more by dense

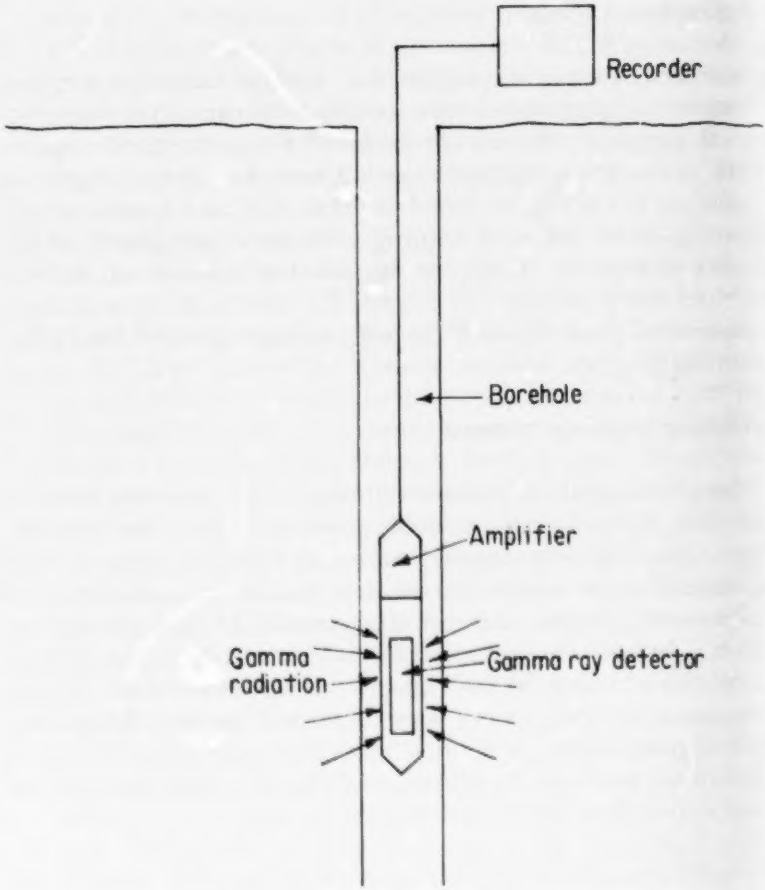


Figure 14-7. – Elements of the natural gamma (gamma ray) logging system.

than by less dense materials and correspondingly fewer rays reach the detector. The gamma ray log can be conducted in cased boreholes and it is sometimes used in place of the SP log to define shale (clay) and non-shale (non-clay) strata in cased boreholes. The gamma and neutron logs are usually run simultaneously from the same sonde and recorded side-by-side. The gamma ray log also infers relative porosity in porous strata with the assumption that high gamma counts are caused by clay filling the pores of the strata. Gamma ray logs are used for correction of gamma-gamma density logs. Gamma ray logs are standard in radiation logging systems.

Truck mounted and portable units are available. The normal logging speed for truck mounted systems is 5 to 10 ft/min (0.025 to 0.05 m/sec).

(2) Gamma-gamma logging.—The gamma-gamma or density logging device measures the response of the geologic medium to bombardment of gamma radiation from a source in the sonde. Electrons in the atoms of the geologic medium scatter and slow down the source gamma rays, impeding their paths to the detector portion of the sonde. Figure 14-8A illustrates the operation of the gamma-gamma device. Since electron density is proportional to bulk density for most earth materials, strata with high bulk densities impede the source gamma rays more than low density strata, produce correspondingly lower counts at the detector, and low readings on the recorder. The primary use of the gamma-gamma log is the determination of bulk density of the materials near the sonde. If bulk density and grain density are known from samples and if fluid density can be determined, the porosity can be calculated. Gamma-gamma logs can also be used for correlation of strata between boreholes.

The gamma-gamma log is best conducted in uncased boreholes using decentralizing devices to keep the sonde against the borehole wall. The system is affected strongly by borehole diameter and wall irregularities, and must be carefully calibrated for the effects of hole diameter, decay of the strength of the radioactive source, natural gamma radiation in the geologic medium, and borehole fluid densities. A caliper log is commonly run to permit calibration for hole diameter. Some logging systems simultaneously display the gamma ray count on one side of the log and bulk density on the other, with the bulk density log automatically compensated for the effects of mud cake and wall irregularity.

(3) Neutron logging device.—The neutron logging device is an active logging system that measures the response of the geologic medium to emission of neutron radiation from a source located in the logging sonde. Neutrons emitted by the source are captured by certain atoms, especially hydrogen nuclei, in the strata near the sonde. Figure 14-8B illustrates the operation of the neutron logging device. Collision of neutrons with atoms of the geologic medium causes emis-

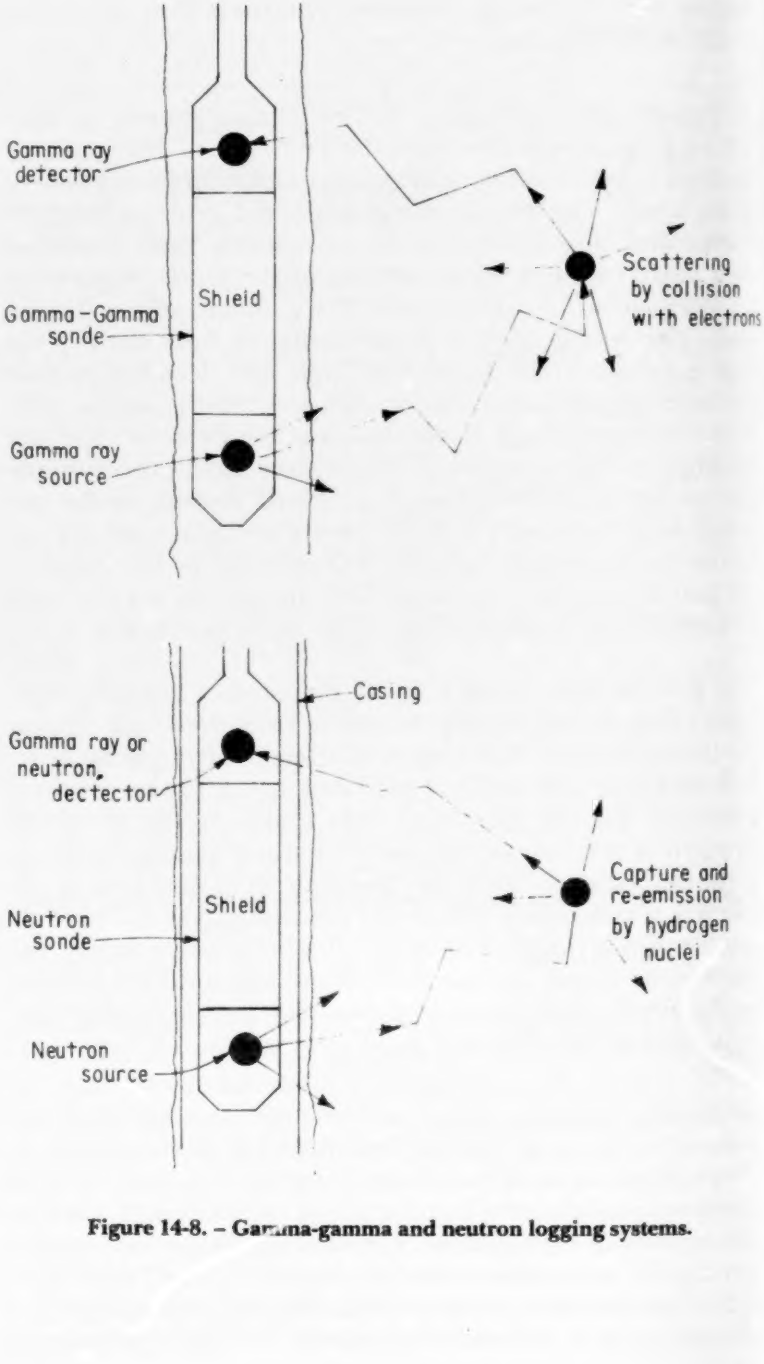

Gamma ray detector
Shield
Gamma-Gamma sonde
Gamma ray source
Scattering by collision with electrons
Casing
Gamma ray or neutron, dectector
Shield
Neutron sonde
Neutron source
Capture and re-emission by hydrogen nuclei

Figure 14-8. – Gamma-gamma and neutron logging systems.

sion of secondary neutrons and gamma rays, a portion of which are picked up at the detector on the sonde. A high concentration of hydrogen atoms near the source captures a greater number of neutrons and produces a smaller counting rate at the detector and a lower reading on the log curve.

Neutron log detectors may be designated to detect gamma (neutron-gamma log) or neutron (neutron-neutron log) radiation. Water and hydrocarbons (petroleum, for example) contain high concentrations of hydrogen atoms. If the fluid in the strata is assumed to be water, the neutron log is an indicator of the amount of water present, and determination of volumetric water content (weight of water per unit volume measured) is its principle use. In saturated materials the neutron log can be an indicator of porosity, the ratio of the volume of void space of the total volume. Bulk densities from gamma-gamma logs, grain densities from samples, caliper log data, and natural gamma log information can be combined with the volumetric water contents from neutron logs to calculate the more commonly used geotechnical parameters of water content by weight, wet and dry density, void ratio, porosity, and saturation.

Neutron logs and natural gamma radioactive logs can be obtained through thick borehole casings and are usually run simultaneously. Figure 14-9 illustrates the format of the tandem logs and typical responses for several strata lithologies. The response in different lithologies of the log curves for the natural gamma and neutron devices is controlled directly by the amount of radioactive material present (especially the clay content) and the fluid content, and indirectly by the porosity and bulk density of the strata near the sonde. For example, the saturated sand of figure 14-9 absorbs neutron radiation, produces a correspondingly low neutron log count, and produces a low natural gamma count because of the lack of clay in its pores.

Neutron activation, or spectral, logs provide spectral analysis of the geologic medium near the borehole to detect the presence of certain elements in the medium. The spectral logging sonde activates a neutron source in bursts of short duration, and activates the gamma ray detector only during the source bursts. As a result, only certain radiation

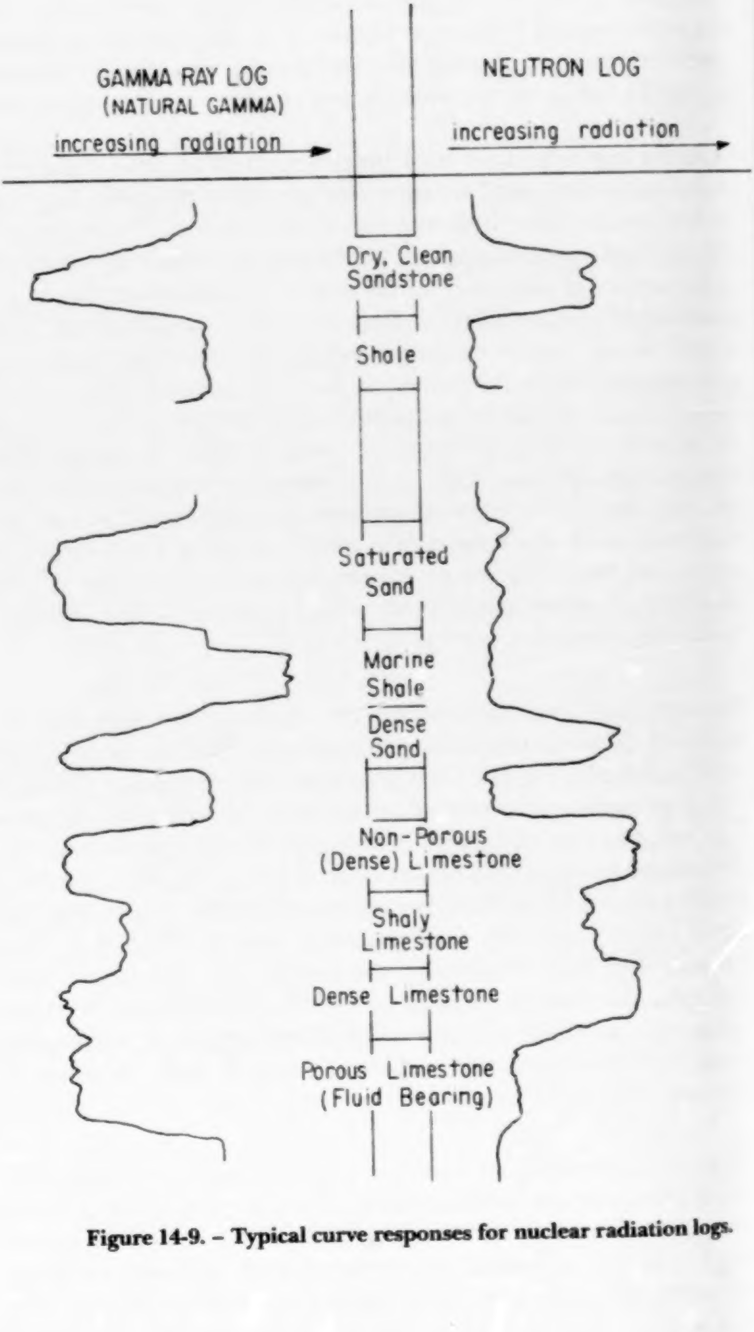


Figure 14-9. – Typical curve responses for nuclear radiation logs.

("prompt" gamma rays) are detected. An analyzer in the system presents a plot of counts vs gamma ray energy. Peaks on the energy/count plot identify specific elements, for example carbon, silicon, magnesium, or chlorine. Spectral logs may have application to ground-water quality investigations.

Acoustic/Seismic Logging Techniques

Wireline acoustic/seismic logging systems use medium to high frequency acoustic (sonic) energy beams emitted from a sonde to image the borehole wall or to obtain seismic velocities of the geologic material in the wall or in the geologic formation some distance from the borehole. Acoustic systems strictly apply to sonic energy generated and propagated in fluid such as air to water. Seismic systems strictly apply to sonic energy propagated in the ground in geologic materials. The three systems discussed in this section are the borehole imaging device, an acoustic system; the acoustic velocity logger, an acoustic and seismic energy system; and the crosshole seismic technique, an acoustic/seismic method.

Application

The borehole imaging and acoustic velocity systems originally were developed for and are still used in petroleum exploration. However, both techniques find application in geotechnical investigations for the evaluation of borehole geologic conditions including attitude and occurrence of discontinuities and solution cavities and in the determination of the effective porosity and the elastic properties of rock from seismic velocity data. The crosshole seismic technique originally was developed as a geotechnical tool. The downhole systems also supply valuable subsurface information for the interpretation of surface-applied geophysical surveys. The frequency of the energy pulse produced by the sonde's tranducer determines whether the energy beams penetrate the borehole wall for acoustic/seismic velocity surveys (medium frequencies) or are reflected totally from the wall for imaging surveys (high frequencies). The borehole imaging and acoustic velocity devices generate compressional (P-wave) energy. The crosshole seismic technique generates P- and S (Shear)-wave energies and calculates their velocities.

Equipment requirements

The acoustic logging systems (borehole imaging and acoustic velocity) are available as services from commercial well logging companies. The tools (sondes) are relatively large and heavy and must be truck mounted. A winch, multi-conductor armored cable and surface electronics and recording systems powered by 115 volt AC electrical supply are also required. The crosshole seismic technique is not a standard wireline service.

Operational costs

Wireline acoustic surveys generally require more field (survey) time than many other logging surveys because the acoustic systems' logging speeds are generally lower (as low as 4 ft/min [0.02 m/sec] for the borehole imaging device). The crosshole seismic technique required the implacement of at least two boreholes to the depth of interest, the use of explosive or other high energy source, computerized interpretation, and borehole deviation surveys.

Acoustic/Seismic logging systems

(1) Acoustic velocity logger.—The continuous acoustic velocity (sonic) logger measures and records the velocity of acoustic energy (seismic waves) in the strata adjacent to the borehole. A transmitter located at one end of the sonde generates an electromechanical pulse which is transmitted through the borehole fluid into the borehole wall and, by refraction, to a receiver located at the other end of the sonde (fig. 14-10). The propagational velocities of the seismic waves can be calculated by noting the arrival times and distance traveled from transmitter to receiver. The devices must be operated in fluid filled borehole. Compressional wave oscilliations set up by the sonde's transmitter in the borehole fluid set up, in turn, oscilliations in the geologic medium of the borehole wall. Compressional, shear and surface waves propagate in and along the wall and then, as compressional waves, back through the borehole fluid to the receiver. Compressional waves have the highest velocity and arrive first, followed by the shear waves and the surface

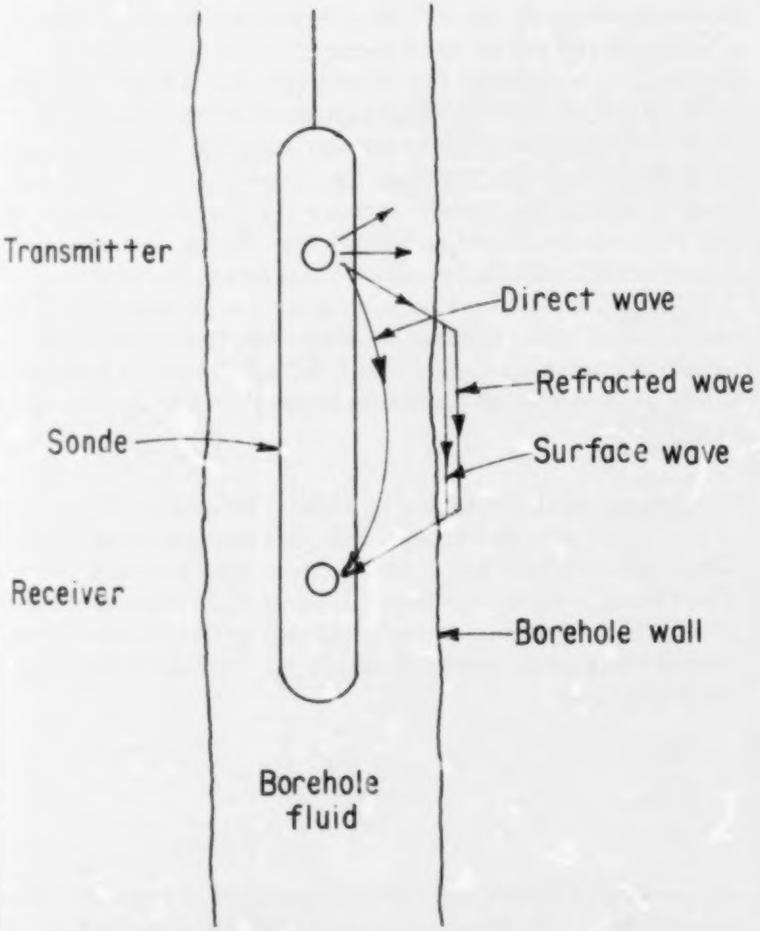


Figure 14-10. – Elements of a simple wireline acoustic velocity device.

waves. Devices with two receivers cancel the borehole fluid travel times so that only the refracted wave paths through the geologic medium are measured. Single-receiver devices require knowledge of the borehole fluid acoustic velocity and borehole diameter for calculation of seismic velocities. The acoustic pulses generated at the transmitter are in the lower ultrasonic range, i.e. around 20 kiloHertz (kHz).

The simplest acoustic logging devices display a single graphical trace or waveform of the arrival of each pulse, and are called amplitude-modulated devices. Intensity-modulated acousting logging devices have been developed to allow recording of the entire continuous acoustic wave train by photographing a cathode ray screen (see fig. 14-11). Intensity-modulated, or 3-D, devices express wave frequency by the width of light and dark bands and amplitude by the degree of light or dark shading (figs. 14-11 and 14-12). The P-wave, S-wave and surface wave arrivals can be discerned on the 3-D records by the experienced eye. Strata or zones of different seismic velocity produce contrasting signatures on the 3-D log. The phyllite zones in figure 14-12 represent softer materials of lower seismic velocity than the metabasalts and produce correspondingly later arrival times. Fractures or other discontinuities can often be seen as disruptions in the bands.

In addition to determining seismic velocities to aid in interpretation of seismic surveys, 3-D logs permit recognition of lithologic contacts, geologic structure and solution cavities. The P- and S-wave velocities can be used directly to calculate the elastic properties of rock, including the Poisson's ratio, Young's modulus, and bulk and shear moduli. For example, Poisson's ratio

$$\mu = \frac{1/2\ V_P^2 - V_S^2}{V_P^2 - V_S^2}$$

where V_P and V_S are the compressional and wave velocities, respectively. The effective porosity of the strata can also be evaluated.

The acoustic velocity devices require a borehole diameter of 3 inches (75 milimeters) or greater and generally cannot be used in cased boreholes. The in situ geologic materials must have compressional wave velocities higher than the velocity of the borehole fluid (approximately 4800 ft/sec [1450 m/sec] for water) for the waves to be refracted and detected. Soils generally do not have sufficiently high seismic velocities for acoustic velocity logging. Logging speeds vary from about 20 to 100 ft/min (0.1 to 0.5 m/sec) at the discretion of the operator. The wave train (trace) type velocity loggers often are equipped with a radiation logging device and caliper on the same sonde for simultaneous recording

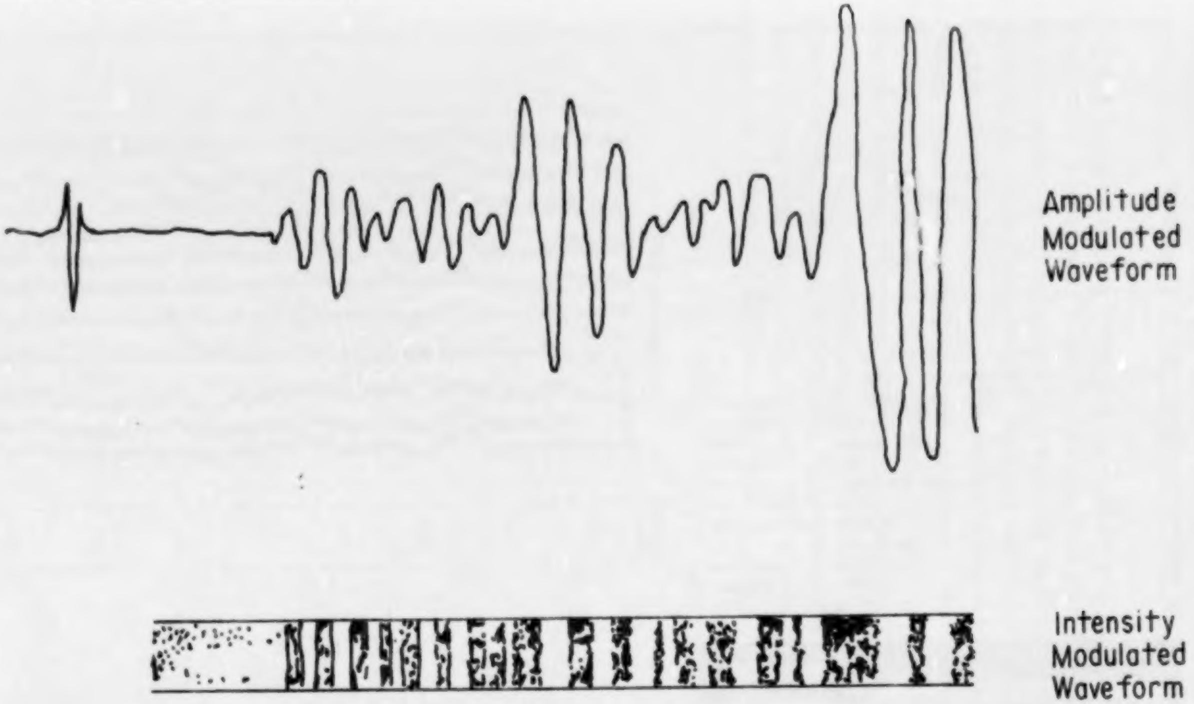
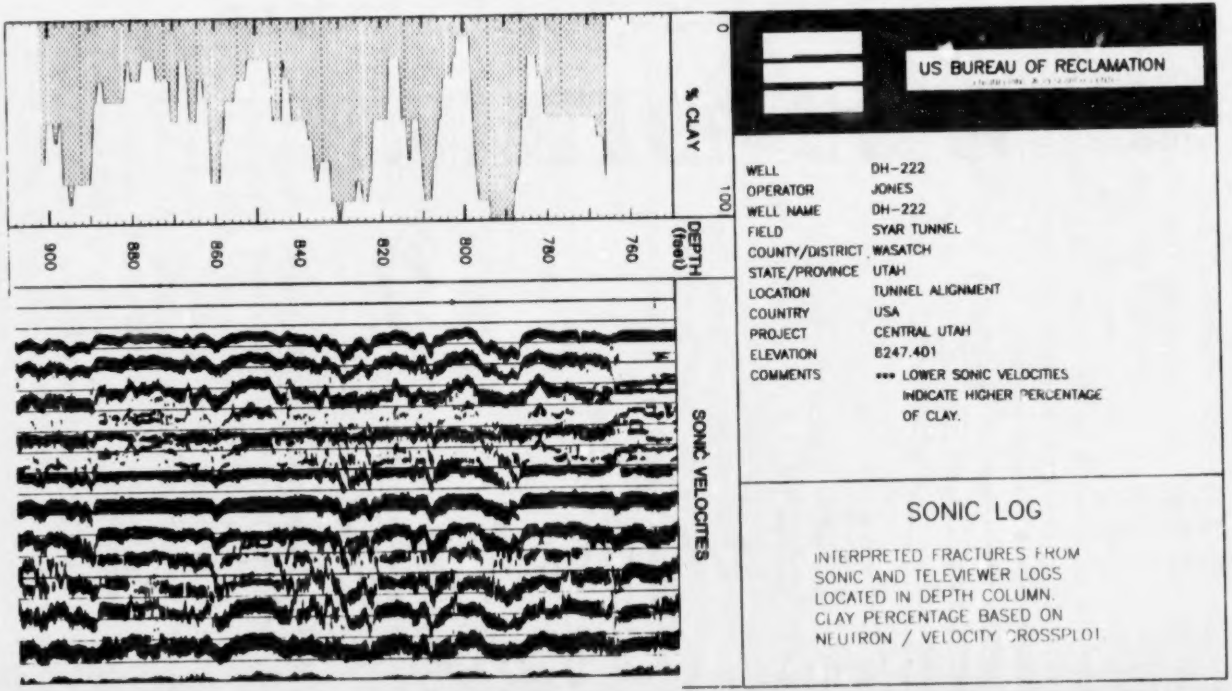


Figure 14-11. – The acoustic velocity logging displays. The intensity modulated waveform wave frequency by the width of the band, amplitude by the degree of light or dark shading of the band.



WELL	DH-222
OPERATOR	JONES
WELL NAME	DH-222
FIELD	SYAR TUNNEL
COUNTY/DISTRICT	WASATCH
STATE/PROVINCE	UTAH
LOCATION	TUNNEL ALIGNMENT
COUNTRY	USA
PROJECT	CENTRAL UTAH
ELEVATION	8247.401
COMMENTS	*** LOWER SONIC VELOCITIES INDICATE HIGHER PERCENTAGE OF CLAY.

SONIC LOG

INTERPRETED FRACTURES FROM SONIC AND TELEVIEWER LOGS LOCATED IN DEPTH COLUMN. CLAY PERCENTAGE BASED ON NEUTRON / VELOCITY CROSSPLOT.

Figure 14-12. – Part of an actual record of intensity-modulated acoustic logging device. Lithologies determined from core samples.

of acoustic and radiation logs and borehole diameter. Additional information concerning the application and interpretation of acoustic velocity devices can be found in OCE [3]; Pickett [5]; Deere et al. [8]; and Geyer and Myung [9].

(2) Acoustic borehole imaging device.—The acoustic borehole imaging device uses high frequency acoustic waves to print a continuous 360 degree image of the borehole wall. Physical changes on the borehole wall are visible as changes in image intensity, or contrast. Proprietary trade names for the acoustic borehole imaging device include "Televiewer" and "Seisviewer." Figure 14–13 illustrates the operation of an acoustic borehole imaging device. A piezoelectric transducer and direction indicating magnetometer are rotated by a motor inside the tool housing at approximately 3 revolutions per second (rps). The transducer emits pulses of acoustic energy toward the borehole wall at a rate of about

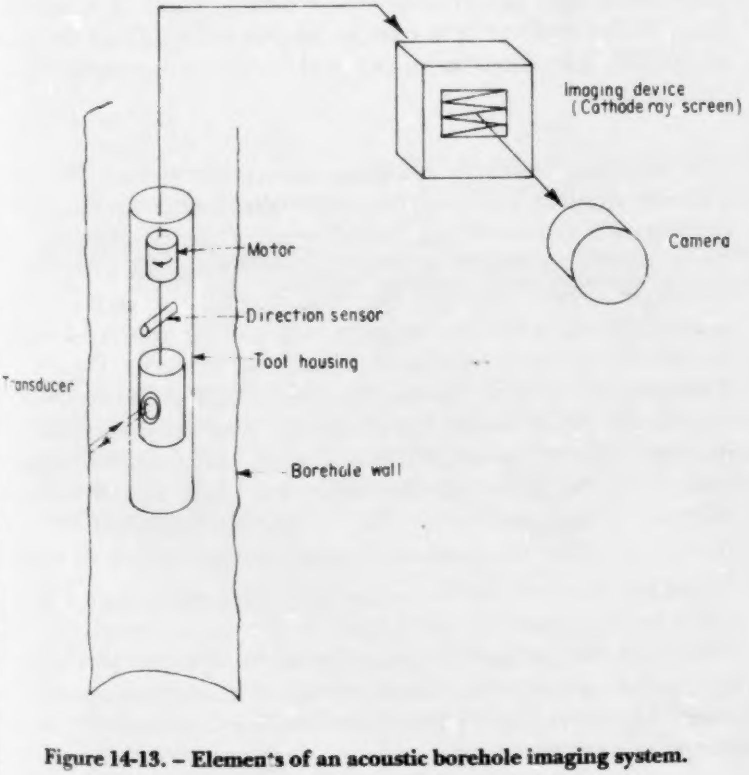


Figure 14-13. – Elements of an acoustic borehole imaging system.

2000 pulses per second at a frequency on the order of 2 megaHertz (MHz). The high frequency acoustic energy does not penetrate the borehole wall. The acoustic beams are reflected from the borehole wall back to the transducer where they are converted to electrical signals and transmitted to the recording device, which consists of an oscilloscope whose cathode ray screen is photographed to create a permanent record of the image of the borehole wall. The intensity of the oscilloscope's electron beam and the image it produces is proportional to the amplitude of the reflected signal, which in turn is a function of the physical condition of the borehole wall, including texture (rough or smooth) and hardness (a function of the elasticity and density of the material). Recent modifications permit recording of data on video tape, displaying data on high resolution fiber optics recorders, and computer image enhancement techniques (Wiley [10]). The image is oriented to magnetic north with every revolution of the transducer. Fractures, cavities and other open discontinuities produce low amplitude acoustic reflections and are readily discerned in their true orientation, width and vertical extent on the image. The tool thus accurately logs discontinuities and cavities intercepted by the borehole.

The acoustic borehole imaging device can detect discontinuities as small as 1/8 inch (3mm) in width and can sometimes distinguish constrasting lithologies. Discontinuities, contacts, and other linear features intercepting the borehole at an angle other than 90 degrees produce a characteristic sinusoidal trace on the image which can be analyzed readily to determine the strikes and dips of the features. Figure 14-14 shows how planar discontinuities of different orientations appear on the acoustic imaging log. Vugs and solution cavities are displayed as black areas on the image and their traces can be analyzed to determine their size (in two dimensions) and percentage of volume in the borehole. The device can also be used to inspect casings and well screens for defects.

The acoustic imaging devices must be operated in a fluid-filled and, unless being used to inspect casing, uncased borehole. The tool must be centered in the borehole by means of spring tensioned centralizers. Logging speed in relatively

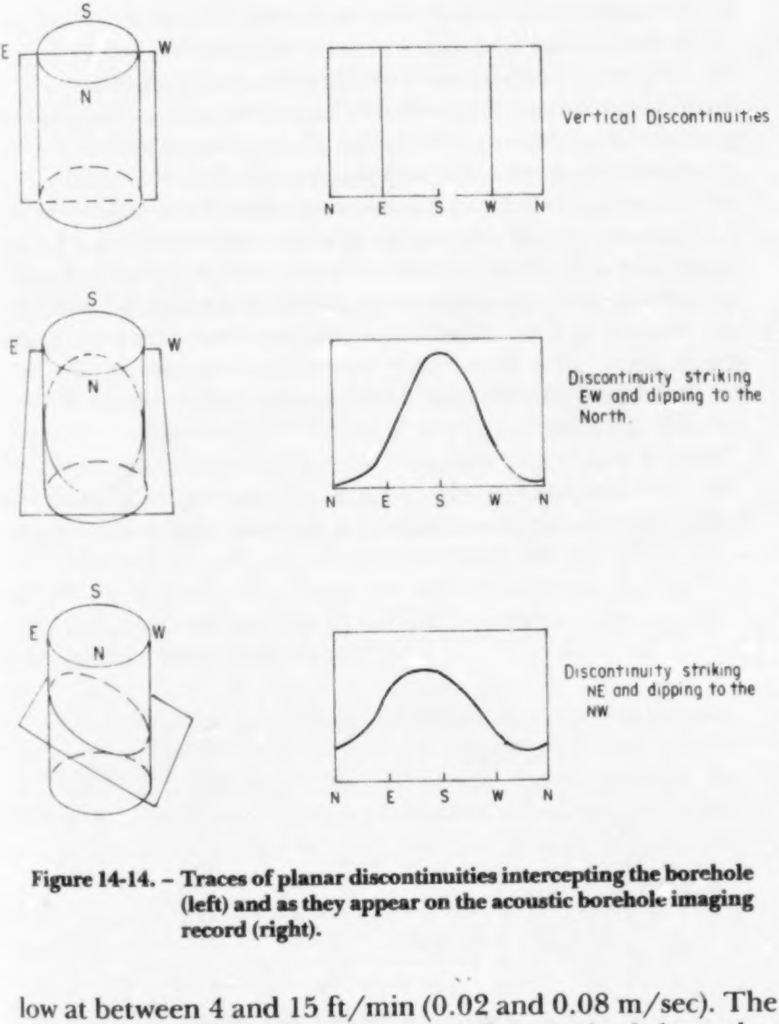

S
E
W
N
N E S W N
Vertical Discontinuities
S
E
W
N
N E S W N
Discontinuity striking EW and dipping to the North.
S
E
W
N
N E S W N
Discontinuity striking NE and dipping to the NW

Figure 14-14. – **Traces of planar discontinuities intercepting the borehole (left) and as they appear on the acoustic borehole imaging record (right).**

low at between 4 and 15 ft/min (0.02 and 0.08 m/sec). The device is a unique tool and can only be acquired through a commercial well logging service company. Standard tool diameter is 3-3/8 inch (85mm) but older units in existence were designed for NX boreholes.

(3) Crosshole seismic tests.—Crosshole tests are conducted by activating a seismic source in a borehole and recording the arrival of the seismic pulse with geophones placed at the same depth in a receiver borehole. Source and geophones are placed consecutively at several depths at regular intervals within the boreholes to determine seismic wave velocities of

each stratum within the zone of interest. Compressional and shear wave velocities can be determined with the crosshole test. Figure 14–15 illustrates the essential features of a croshole seismic test. The seismic source may be either an explosive device or a mechanical system. Explosives are excellent P-wave sources. Explosives and other impulse-type sources also produce S-wave energy but the S-waves are difficult to recognize. Vibrators are the best source of S-waves. Crosshole geophones are configured in a triaxial arrays are used because directional detectors are necessary to identify the S-wave arrival. Two or more receiver holes are sometimes used. The recording system commonly consists of a multichannel seismograph and a recording oscilloscope to record the data.

The raw data of crosshole tests are the times required for P- and S-waves to travel from the seismic source in one bore-

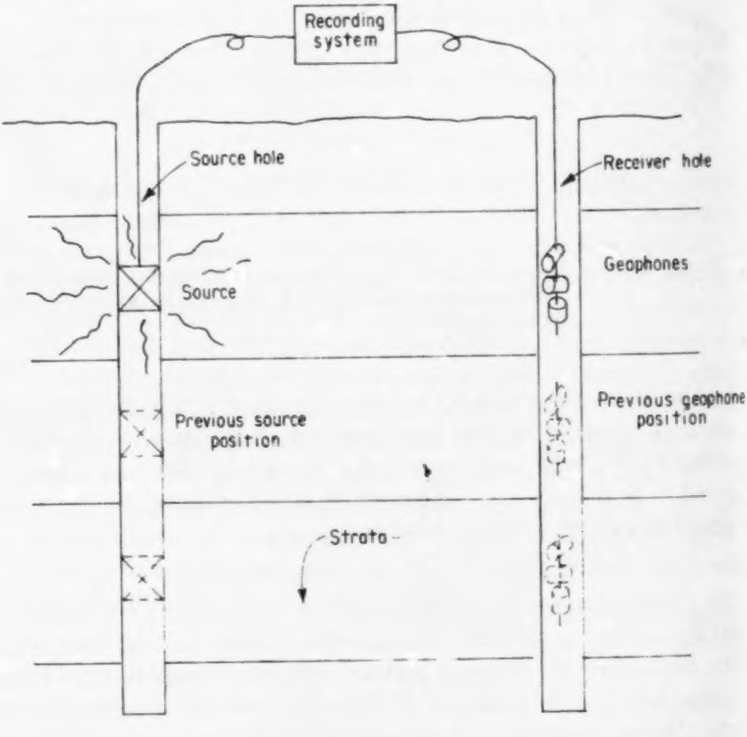


Figure 14-15. – Essential elements of crosshole seismic test.

hole to the detectors in the receiver hole or holes. The corresponding P- and S-wave arrival times can be used to calculate seismic velocities as the ratios of distance to travel time, assuming the arrivals are direct (non-refracted) arrivals. If refraction through a faster stratum occurs, true velocities must be calculated using Snell's law, similar to surface refraction seismic calculations (Electrical Logging Techniques section). A computer program which automatically accommodates direct and refracted waves and calculates true velocities consistent with all the data is often used to interpret crosshole seismic data (Butler et al. [11]).

Travel times obtained in crosshole tests can be resolved to within 0.5 milliseconds (ms) for P-wave and 1.0 ms for S-wave velocities. P-wave accuracy is commonly within 5 to 10 percent and S-wave within 10 to 15 percent of true values. Borehole spacing (distance) is critical in crosshole tests. As a rule, spacing should be no greater than 50 ft (15m) nor less than 10 ft (3m). Borehole deviation surveys should be conducted prior to testing to establish precise spacing distances at each shotpoint depth.

Crosshole tests have several applications in engineering geology. S-wave crosshole tests provide data to determine material properties for static and dynamic stress analysis. In addition to providing true P-and S-wave velocities at different depths, crosshole surveys can detect seismic anomalies such as zones of low velocity underlying a zone of higher velocity or a layer with insufficient thickness or velocity contrast to be detected by surface refraction tests.

Borehole Optical Systems

Borehole wireline optical logging systems include borehole film-recording cameras and borehole television cameras. Optical logging systems permit viewing and recording of visible features in the walls of dry or water-filled boreholes, wells, casing, pipelines, and small tunnels.

Application

Borehole cameras are an important supplement to geotechnical drilling and sampling programs because the systems allow the determination of geologic and constructional features in place and in relatively undisturbed condition. The aperture (width), true orientation (strike and dip), and frequency (number per foot of borehole) of discontinuities in the rock mass can be determined with optical logging systems. The effective, or fracture porosity associated with open discontinuities can be derived also. The occurrence and size of solution cavities, the classification of rock type from visual examination of rock and mineral textures and color in the borehole wall, and the location of stratigraphic contacts can be determined. Other geotechnical applications include the determination of the conditions of the contacts of rock or soil against concrete and the condition of the interior of rock or concrete structures. Optical logging systems permit the recognition and description of soft or open zones in rock that may be overlooked in normal drilling and sampling operations. Zones of poor sample recovery or of drilling fluid loss can be investigated with the systems.

Equipment requirements

Borehole wireline optical systems are relatively expensive to purchase but provide rapid logging capability which reduces field survey time and expense. The television systems permit immediate (real time) inspection and interpretation of subsurface features or, if desire, the record may be video taped for later viewing in the office or laboratory. Borehole film camera systems require processing of the film with a corresponding lag time between logging and interpretation. Quantitative interpretation of geologic features of camera-logged boreholes can be time consuming and is usually more costly in terms of man hours than the actual field logging operations. Qualitative interpretation required much less time. Several boreholes of hundred-foot depth can be logged in an average day.

Borehole optical systems

(1) Borehole television.—Borehole television systems provide real time viewing of the interior of a dry or water filled borehole. The typical system (fig. 14–16) consists of a downhole probe and surface-mounted cable winch, control unit, power supply, television monitor and video tape unit. The

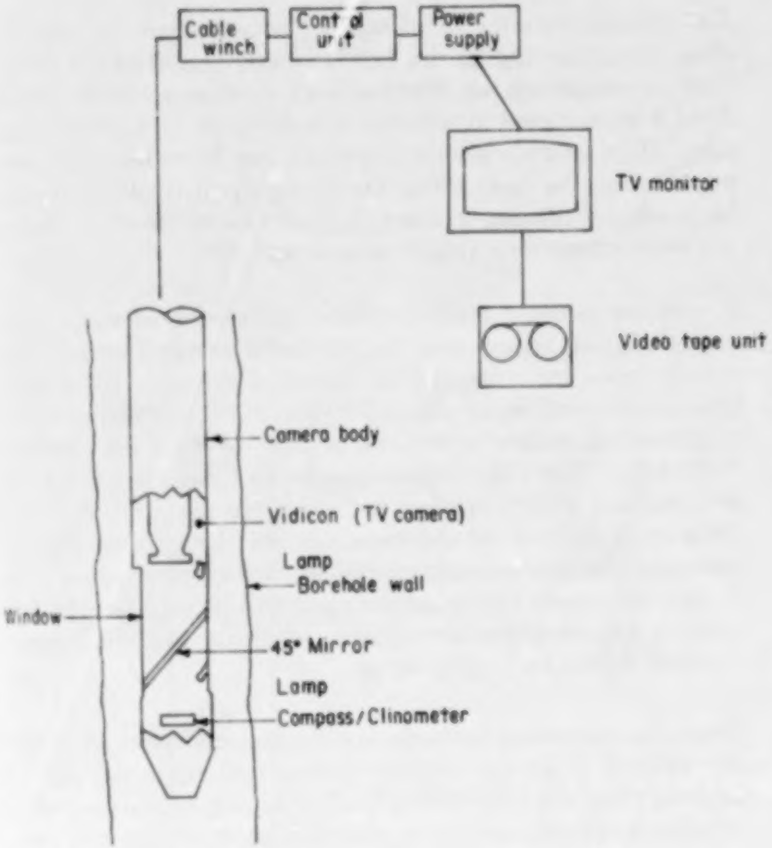


Figure 14-16. – Elements of a borehole television logging system.

downhole probe contains a vidicon (television camera) facing vertically downward toward a partially reflecting mirror inclined 45 degrees to the axis of the probe. A compass/clinometer used to determine the orientation of features in the borehole wall and the inclination of the borehole can be viewed selectively through the mirror by varying the relative intensities of lamps located above and below the plane of the mirror. A motor within the probe rotates the vidicon and mirror assembly (or the mirror only) 380 degrees in a reciprocating fashion (clockwise, then counterclockwise) as the probe is lowered or raised within the hole. The operator controls the motion and logging speed of the probe. A full image of the borehole wall is obtained with each rotation.

An optional viewing head may be attached to the probe to allow axial viewing of the hole directly ahead of the probe. The probe ascent or descent and vidicon rotation can be slowed or stopped at will for examination of borehole features. The entire viewing sequence can be video taped during the logging operation. Hard copy prints of a scene can be made by photographing the television monitor. Scenes are monochromatic (black and white).

There are commercially available borehole television cameras designed to operate in NX boreholes. The stainless-steel probes are designed to function in water filled boreholes at maximum depths of 1300 to 1600 ft, (400 to 485m) representing water pressures of 560 to 690 psi (3860 to 4760 kPa). The vidicon lens can focus from the probe window surface to infinity but the effective maximum viewing distance is limited by the capability of the probes' lighting systems. The horizontal resolution of the television systems in approximately 600 scan lines per full picture height. The systems reportedly can resolve borehole wall features as small as 0.002 inch (0.05mm).

Borehole television systems are commonly used to inspect the walls of large concrete and rock structures for defects, to determine the effectiveness of grouting operations of the condition of concrete joints, to estimate the volume of cavity within a rock or soil mass, and to inspect the screens of water wells. Television images can be used to determine attitudes of discontinuities but are less effective for complete borehole mapping than the borehole film camera systems which portray the borehole walls as discrete, full color separate images more suitable for detailed study and measurement. Further discussion of a borehole television system can be found in Ellis [12].

(2) Borehole film camera.—The borehole film camera produces consecutive, overlapping, 16 mm color still photographs of 360 degree, 1-inch (25 mm) sections of the walls of NX or larger boreholes. The system consists of a downhole probe and surface mounted lowering device, metering units, and power supply. Figure 14–17 illustrates the downhole probe. The stainless-steel probe consists of a 16-mm movie camera and lens mounted in line with the probe axis

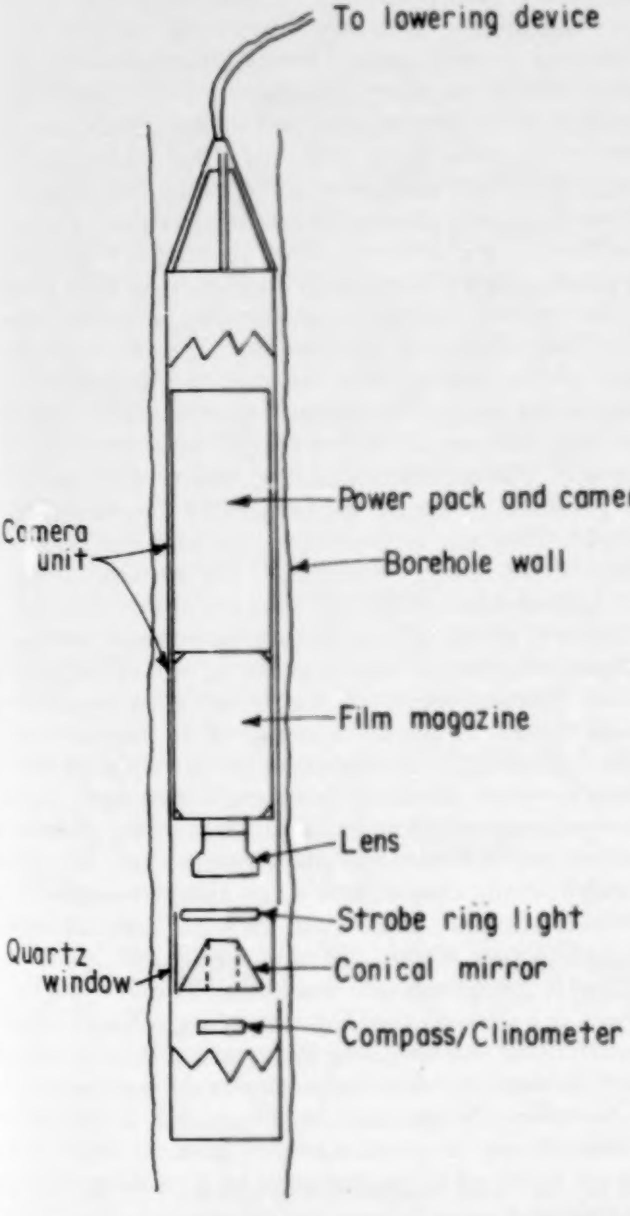


Figure 14-17. – Schematic drawing of NX borehole film camera in borehole.

and facing a truncated conical mirror, which is surrounded by a cylindrical quartz window. A film magazine and film drive mechanism are mounted above the camera in the probe housing. A ring shaped strobe illuminates the borehole wall in synchronization with the camera's film advance. Film advance, probe movement, and strobe lighting are synchronized to expose a frame every 3/4 inch along the hole, so that a 1/4-inch (6 mm) overlap of every 360 degree, 1-inch (25 mm) section photographed is achieved. The truncation of the conical mirror allows the camera simultaneously to photograph a compass/clinometer located directly beneath the mirror. Images produced on the movie camera are viewed individually (stillframe) on a special projector of the image of the mirror face onto a flat film plane. The outer ring of the image "doughnut" represents the base and the inner ring the top of the 1-inch (25 mm) section of the borehole wall. Planar discontinuities intersecting the borehole wall produce a trace on the image like the shaded curve of Figure 14–18 (top). In a vertical borehole the outer and inner rings of the image "doughnut" are horizontal traces. Points of intersection of planar discontinuities with a ring thus define the strike of the feature in vertical boreholes. The compass area in the center of the image of Figure 14-18 permits determination of the bearing of intersecting planes with respect to north. The dip of the feature can be determined graphically by counting the number of successive frames in which the feature appears. A steeply dipping plane intersects several frames, a gently dipping plane only a few frames and a horizontal plane one frame. The thickness or width of the discontinuity can also be measured directly from the image. Data from inclined boreholes must be corrected to true strike, dip, and width, for which purpose computer programs are available. The NX borehole film camera is a proven tool for supplying subsurface data in difficult drilling and sampling programs and for providing complete quantitative information on discontinuities and borehole anomalies. Strike can be measured accurately to about 1 degree, dip (or inclination) to about 5 degrees and thickness or width of discontinuities to a hundredth of an inch or better.

In operation, the borehole film camera probe is lowered to the bottom of the hole and raised by a hand cranked winch

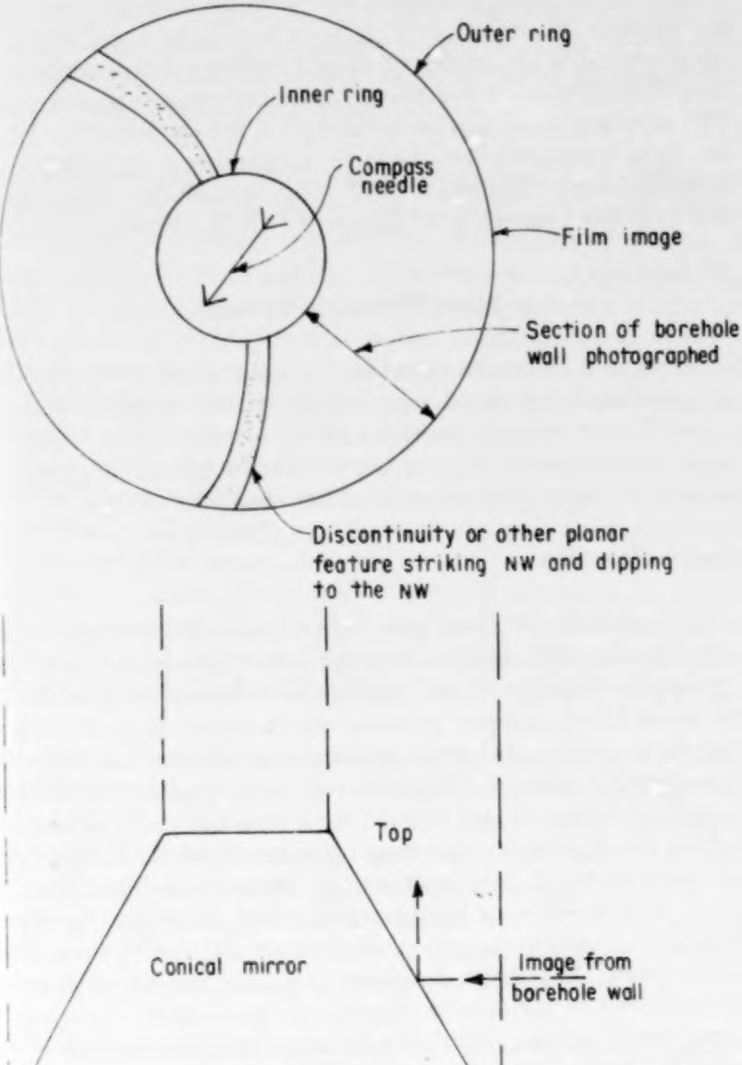

Outer ring
Inner ring
Compass needle
Film image
Section of borehole wall photographed
Discontinuity or other planar feature striking NW and dipping to the NW
Top
Conical mirror
Image from borehole wall
Base

Figure 14-18. – Projection of borehole wall image into the film plane from the conical mirror of the borehole film camera.

at a logging speed of between 5 and 10 ft/min (0.02 to 0.05 m/s). Approximately 75 to 90 ft (23 to 28m) of borehole can be photographed with a single load of film. Since the camera has no shutter or light metering capability, the aperture must be preset to satisfy lighting requirements of hole diameter and reflectivity of the borehole wall materials. The lens aperture can be set at F/2.8 for dark rock to F/22 for light colored rock and the maximum range (depth of field) is about 12 inches (300 mm). Boreholes larger than NX require centering of the probe in the hole.

Other Wireline Systems

This section discusses some, but not all, wireline devices that are available for supplementary or special purpose applications. Other systems include the borehole caliper, the borehole temperature logger, the borehole gravity logger, the magnetic logging systems, and borehole surveyors.

Borehole caliper

The borehole caliper provides a continuous record of changes in borehole diameter determined by a probe equipped with tensioned mechanical arms or with an acoustic transducer. Caliper or borehole diameter logs are one of the most useful and simplest of all techniques employed in borehole geophysics. They provide a means for determining inhole conditions and should be obtained in all borings in which other geophysical logging is anticipated. Caliper logs provide indirect information on subsurface lithology and rock quality. Borehole diameter varies with the hardness, fracture frequency, and cementation of the various beds penetrated. Borehole diameter logs can be used to accurately identify zones of enlargement (washouts) or construction (swelling) or to aid in the structural evaluation of an area by the accurate location of fractures or solution openings, particularly in borings with core loss. Caliper logs also are a means of identifying the more porous zones in a boring by locating the intervals in which excessive mud filter cake has built up on the walls of the borehole. One of the major uses of borehole caliper logs is to provide information by which other geophysical logs can be corrected for borehole diameter effects, for example in the calibration of gamma-

gamma density logs. Caliper logs also can be used to evaluate the inhole conditions for placement of water well screens, for the positioning of packers for pressure testing in foundation investigations for dams or other large engineering structures, and for determination of required grout volumes in solution or washout zones.

Mechanical calipers are standard logging service equipment available in one-, two-, three-, four-, or six-arm probe design. Multiple-arm calipers convert the movement of feelers or bow springs to electrical signals by means of potentiometers in the probe. The electrical signals are transmitted to a surface recorder through an armored conducting cable. Some caliper systems average the movement of all the arms and record only the change in average diameter with depth, and others provide readouts of the movements of the individual arms as well as an average diameter. The shape or geometry of the borehole cross section can be determined with the individual caliper arm readings. A six-arm caliper capable of detecting diameter changes as small as 1/4 inch (6mm) in 6-inch (13mm) to 30-inch (760mm) diameter boreholes produces a record like that shown on figure 14–19. The six arms are read as three pairs so that the diameter in three directions is recorded in addition to the average diameter.

Mechanical calipers are lowered to the bottom of the borehole in closed position, the arms are released, and the tool is raised at a rate of 15 to 20 ft/min (0.08 to 0.1 m/s). Permissible hole diameters vary with the complexity and number of arms of the probe but units are available for logging boreholes of 2 to about 36 inch diameter (50 to 900mm). The calipers must be calibrated against a known minimum and maximum diameter before logging.

The acoustic caliper measures the distance from a probe-mounted acoustic transducer to the borehole wall using the acoustic velocity of the transmitted individual diameter readings for each of four transducers mounted 90 degrees apart and also averages the four readings. A special purpose acoustic caliper designed for large or cavernous holes (6 ft to 100 ft [1.8 to 300m] in diameter) uses a single rotating transducer to produce a continuous record to hole diameter changes.

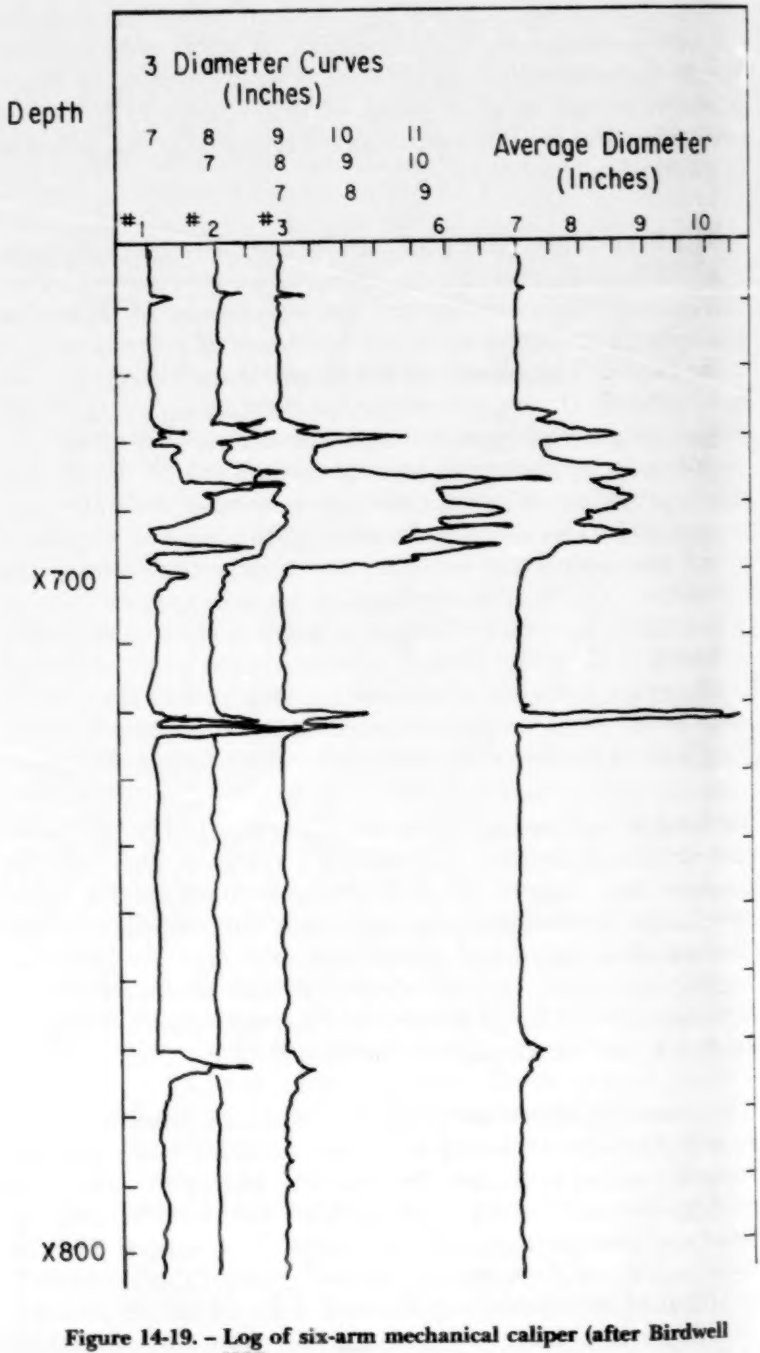


Figure 14-19. – Log of six-arm mechanical caliper (after Birdwell [13]).

Borehole fluid temperature logger

The standard borehole fluid temperature logging device continuously records the temperature of the water or drilling mud in an open or cased borehole as the logging sonde is raised or lowered in the borehole. The standard, or gradient, device uses a single thermistor (thermal resistor) mounted within the sonde to respond to temperature variations in the fluid passing over it. A small change in temperature produces a large change in resistance which is converted to a change in electrical current and transmitted through a conducting cable to strip chart recorder at the surface. Gradient type devices record the actual fluid temperature. A differential device is also sometimes used to record differences in temperature between two positions in the borehole by the use of two thermistors or one thermistor and a memory unit within the control module. The log produced by the gradient device shows temperature in degrees Fahrenheit (F°) as a function of depth.

Temperature logging is usually performed prior to standard geophysical logging operations to permit correction of other logs, for example the resistivity logs, for the effects of borehole fluid temperature. Temperature logs can also be used to indicate the source and movement of fluids into or out of the borehole; to identify zones of waste discharge or thermal pollution in ground water; and to locate grouted zones behind casing by responding to the heat produced by the hydration of the setting cement.

The temperature probe must be calibrated against a test fluid of known temperature immediately before temperature logging commences. Borehole fluids must be allowed to reach a stable temperature after drilling operations before logging can be conducted. Open boreholes take a longer time to stabilize because of the differences in thermal conductivity of the various strata encountered, and therefore most geophysical calibration temperature logs are run in cased holes. The logging speed of temperature probes is relatively slow at 3 to 4 ft/min (0.01 to 0.02 m/s) because the thermistors require time to respond to thermal changes. Devices are available to log holes as small as 2 inches (50mm) in diameter. Gradient type temperature loggers are standard services of well logging service companies.

Borehole gravity logger

A borehole gravity meter (or gravimeter) detects and measures variations in the force of gravity associated with changes in bulk density of the medium surrounding tool. The device determines the bulk density of a large volume of soil or rock between a pair of measuring stations in the borehole (fig. 14–20). The bulk density is proportional to the measured difference in gravity (*G*) between the two stations and inversely proportional to the vertical distance (*Δ*) between the stations. The borehole gravity meter has been used primarily by the oil industry for the determination of porosity (especially fracture and vugular porosity). Porosity is calculated using standard equations relating bulk density, fluid density

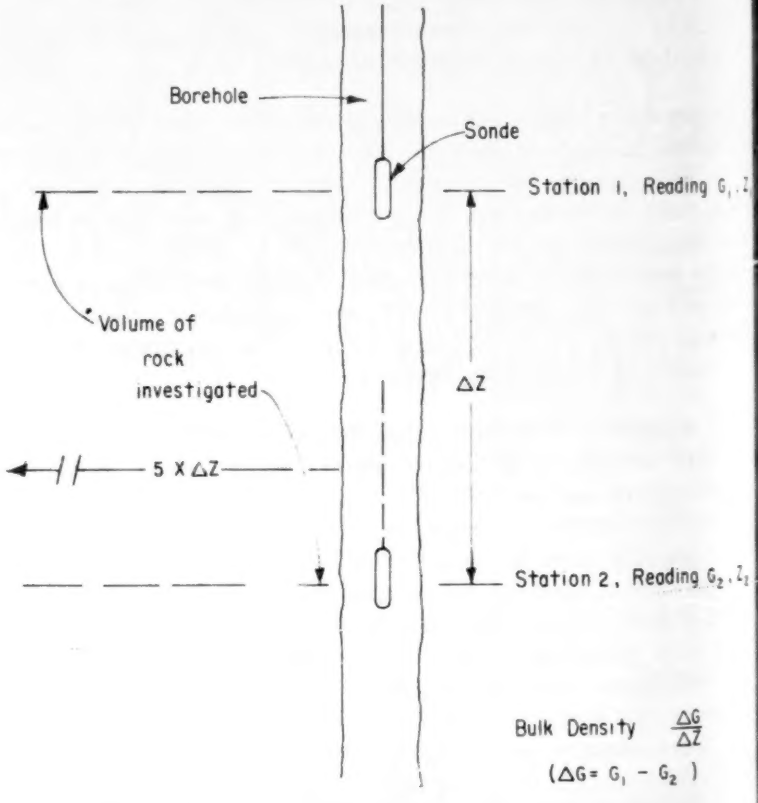


Figure 14-20. – Elements of borehole gravity logging.

and specific gravity of solids (matrix density). Although density and porosity are also provided by the gamma-gamma density logger (see Nuclear Radiation Logging Techniques), the large volume and radius of investigation of the gravity meter produces data less affected by borehole effects such as mudcake and irregular hole diameter. Gravity meter density determinations are more representative of the geologic medium away from the borehole than are gamma-gamma logs. The radius of investigation of the gravity meter is estimated to be approximately five times the difference in elevation between the measuring stations (see fig. 14–20).

The borehole gravity meter is not a continuous-recording instrument. The tool must be positioned at a preselected measurement station, allowed to stabilize, and then a measurement taken. Measurement intervals are commonly 10 ft (3m) in shallow holes to 100 ft (30m) in deep holes. Approximately 10 minutes are required to make a reading at each station. Instrument dial readings are converted to gravity values with a conversion table. Bulk density is then calculated using the difference in gravity values and depth between the two stations. The best precision attainable with the commercially available borehole gravity meter is about 0.010 milligals (mgals, a unit of force of gravity). Usually, several (two or three) traverses are made in the hole at repeated stations and the values averaged. The precision of the method decreases with decreasing distance between measuring stations.

Borehole gravity meters require a minimum borehole diameter of 6 inches and a two- or three-man crew. Surveys may be conducted in cased or uncased holes. Several corrections to the data are necessary including corrections for earth-moon tides, instrument drift, borehole effects, subsurface structure gravity anomalies, hole deviation from vertical, and the free-air vertical gravity gradient. The instrument should be calibrated after 45 min to 2 hrs of logging to correct for drift and tides. The borehole gravity logger is available commercially but is not widely used (not a standard logging service) and is still the subject of research. Its apparent advantage over other bulk density/porosity loggers are the lessening of borehole effects and the greater volume of investigation. Rasmussen [14] presents a good discussion of the principle, field operation, and limitations of the borehole gravity meter. Information is also available in Jones [15] and McCulloh et. al. [16].

Application and Data Acquisition

This chapter has described the tools available. Various projects and data collection requirements may differ. Figure 14-21 provides a geophysical matrix for the assignment agreed upon by the design and exploration teams. This is the format to be used to formulate that assignment.

GEOPHYSICAL EXPLORATION MATRIX
PHASE I

Project: ____________________

Feature: ____________________

Proposed geophysical exploration objective and scope of work: Locate ground water, faults, fracture zones, and determine heterogeneity of the tunnel rock

Type geophysics	Objective	Resolution	Unit cost[1]	Survey cost[1]	Time frame of survey[2]	Contractor	Relative cost effectiveness	Remarks
Self potential	Locate zones of moving water and mineralized fault and shear zones	30% of depth – unlimited – depends on size of source	[1]	[1]	[2]	General	High	
Electromagnetic conductivity (EM-34) & d-c resistivity	Locate zones of high and low conductivity – saturated and mineralized zones – water table	Vertical 30% of depth – lateral 20′ penetration 150′	[1]	[1]	[2]	General	High	
Seismic refraction	Low velocity zones correlate with fracture and fault zones	30′ lateral target – penetration 150′	[1]	[1]	[2]	General	Medium	
Magnetics	Faulted and sheared mineralized zones	Large magnetic zones at depth or small shall features	[1]	[1]	[2]	General	High	

---

[1] The geophysical surveys will all be performed at the same time at approximately $x,xxx/day with a total cost of $xxx,xxx/day X number of days.

[2] The phase I geophysical surveys, fieldwork, are estimated to be completed within a x-week timeframe.

Figure 14-21. – Example for GEOPHYSICAL EXPLORATION MATRIX – PHASE I.

BIBLIOGRAPHY

] Schlumberger Limited, *Log Interpretation, Vol. 1, Principles*, Schlumberger Limited, New York, NY, 1972.

] Keller, G. V. and Frischknecht, F. C., *Electrical Methods in Geophysical Prospecting*, Pergamon Press, Oxford, 1966.

] Office, Chief of Engineers, *Geophysical Exploration*, Engineer Manual EM-1110-2-1802. Washington, D. C., 1979.

] Tixier, M. P., "Electric Logging," in *Subsurface Geology in Petroleum, a Symposium*, edited by J. D. Haun and L. W. LeRoy, Colorado School of Mines, Golden, CO, 1972.

] Pickett, G. R., "Resistivity, Radioactivity and Acoustic Logs," in *Subsurface Geology: Petroleum, Mining, Construction*, ed. by L. W. LeRoy et. al., Colorado School of Mines, Golden, CO, 1977.

] Scientific Software Corporation, *Well Logging Manual*, U. S. Geol. Survey, Contract No. GS-14-08-0001-13926, Sept. 1975.

] Hunt, Richard W., "Use of Borehole Geophysical Methods in Determining In Situ Bulk Densities and Water Contents in Unconsolidated Materials," U. S. Army Engineer Waterways Experiment Station. MP S-77-18, Vicksburg, MS, Sept 1977.

] Deere, D. U., A. H. Merritt, and R. F. Coon, "Engineering Classification of In-Situ Rock," Technical Report No. AFWL-TR-67-144, Air Force Weapons Laboratory, New Mexico, Jan. 1969.

] Geyer, R. L. and J. I. Myung. "The 3-D Velocity Log; A Tool for In-Situ Determination of the Elastic Moduli of Rocks," in Proc., 12th Symposium on Rock Mechanics, University of Missouri, Rolla, Amer. Inst. Mine., Met., Pet. Engineers, Inc., New York, NY, 1971.

[10] Wiley, Ralph, "The Borehole Televiewer: an Update on Application," *World Oil*, Vol. 192, 1981.

[11] Butler, D. K., Skoglund, G. R., and Landers, G. B., "Crosshole: An Interpretive Computer Code for Crosshole Seismic Test Results, Documentation, and Examples," Miscellaneous Paper No. S-78-6, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, MS, 1978.

[12] Ellis, M. C., "Borehole Television," in *Subsurface Geology: Petroleum, Mining, Construction*,. ed. by L. W. LeRoy et al., Colorado School of Mines, Golden, CO, 1977.

[13] Birdwell Division of Seismograph Service Corporation, "Logging Capabilities and Services," Commercial Brochure, Birdwell, Tulsa, OK, undated.

[14] Rasmussen, N. F., "Borehole Gravity Surveying Planning and Operations," Proceeding, SPWLA 14th Annual Logging Symposium, 1973.

[15] Jones, Bill R., "The Use of Downhole Gravity Data in Formation Evaluation," *The Log Analyst*, Vol. XIII, No. 6, Nov-Dec., 1972.

[16] McCulloh, T. H. et al., "The U. S. Geological Survey–LaCoste and Romberg Precise Borehole Gravimeter System—Test Results," U. S. Geol. Survey Prof. Paper 575-D, pp. D101-D112, 1967.

Chapter 15

STANDARDS FOR CARE, RETENTION, AND DISPOSAL OF DRILL CORE AND SUBSURFACE SOIL AND ROCK SAMPLES

General

The standards outlined below will be used to determine the care, retention, and disposal of drill core and samples secured in explorations during the investigations for analysis, design, and construction of Reclamation structures.

These standards apply to all foundation explorations for structures, such as dams, canals, tunnels, power and pumping plants and construction materials investigations including riprap and borrow, and investigations of the adequacy or safety of existing structures. Samples secured in investigations for concrete aggregate, pozzolan, land classification, and drainage (except for drainage structures) are excluded.

These standards are intended to maximize care of samples and cores, to minimize storage costs, meet minimum technical requirements, and avoid unnecessarily long storage periods. Occasions may occur, however, in which their application would result in unnecessary handling or excessive costs. In such cases, the Regional Director should arrange handling appropriate to the special conditions, provided no damage or deterioration of samples or core will result.

These standards are formulated with principal reference to rock and soil core and samples (A-, B-, N-, size up to 12 inch) taken without special sampling sleeves, tubes, or containers. When undisturbed samples taken in sleeves or containers, or undisturbed hand-cut samples are specifically intended for laboratory examination or testing to supply design data, such samples should be taken, prepared, cared for, and handled in accordance with USBR 7100 or USBR 7105 in the *Earth Manual*. Undisturbed samples should be shipped to the Division of Research and Laboratory Services, Denver Office, immediately to avoid deterioration, change in physical properties, and adverse affects on test results. Appropriate logs, sample data sheets, or other pertinent information shall be submitted with the samples.

Location of Storage Facilities

The preparation and retention of an adequate log or description of the core or samples treated in the following paragraphs are prerequisites to initiating storage and disposal procedures. Depending on the types of samples and material sampled, such as slaking materials, shales, or sediments that break down upon drying and lose their in-place characteristics during storage, it may be less expensive to drill new holes than to store large quantities of core that would be seldom if ever looked at or would lead to misleading interpretations if inspected after years of storage.

Core and sample storage facilities should be planned with the objective of providing storage at as few points within each region. Each storage facility will serve as large a geographic area, project, or group of projects as practicable. The requirements and criteria listed below should be used for planning and selecting the storage facility.

General Core and Sample Storage Location Requirements

The following are the general requirements for storage of core and samples:

1. Provide minimum storage conditions (See next section, Conditions of Storage).

2. Eliminate unsupervised storage. The storage facility should be at the site of a project, investigation, other Reclamation office, or in the same town.

3. Reduce to a minimum the need for transfer of core and samples from one storage facility to another as work on a structure site or project progresses through successive stages of investigation and construction.

4. Provide accessibility so that minimum travel is required by Reclamation personnel and other authorized individuals, such as prospective bidders on construction

specifications, and permit easy examination of the core and samples.

5. Before constructing or acquiring new space, canvass existing (Government-owned) unused space, or space initially provided for other purposes but adaptable to core and sample storage. (Examples: Lower floors and galleries of many power and some pumping plants; retention of a building erected for temporary use during construction).

Storage During Investigations

Core and samples should be kept at the nearest existing storage facility. A new storage facility should be established only if required by factors such as geography, amount of core and samples anticipated, duration of investigation or convenience of access by engineers and geologists of a new field investigation office. In some instances during periods when actual drilling and sampling operations are in progress, temporary storage at the site may be required to facilitate logging, selection of samples, or ready reference while geologic, soils, or other field studies are in progress. Such temporary onsite storage must be limited to short periods of actual need and must not result in damage or deterioration of the core and samples.

When a field office maintaining core storage facilities is closed following preliminary investigations, core and samples no longer required should be eliminated (See section entitled Retention of Rock Core and Samples), and the remaining core and samples should be transferred to a location where they can be stored most economically. When more extensive exploration is resumed, the core should be reexamined and in some cases must be relogged to relate it to more advanced techniques of geologic appraisal.

Storage During Construction

As the specifications issuance and construction stage approaches, core and samples secured during investigation stages should remain at their current storage facilities unless the Regional Director or Construction Engineer requests their transfer to the construction office to facilitate inspection by prospective bidders or for reference and study by their staffs during construction operations.

As the close of the construction stage approaches, the Construction Engineer should arrange for the Project or Regional Geologist to select, if required, special samples for future research laboratory testing (See Retention of Rock Core and Samples). Note: Sample selection at this time is more satisfactory than later when personnel most familiar with the core, samples, and foundation conditions are no longer available.

At the close of construction stage, transfer of responsibility for continued operation of the structure or project from the Construction Engineer to the appropriate O&M official must include specific arrangements for continued storage of core and samples until applicable core and sample retention criteria have been met. The core and samples should remain at the current storage facility unless circumstances warrant transfer (such as elimination of or higher priority use of the space).

Storage During Operation and Maintenance

The O&M official directly responsible for the structure, group of structures, or project will maintain all core and samples in storage until length of storage requirements have been met. That office will initiate immediately the procedures outlined under Disposal of Core and Samples.

In the event that responsibility for the structure is to pass from Reclamation to another public or private agency such as a water users' association before the applicable standard core retention periods have expired, the last Reclamation official having responsibility for the structure will request the Regional Director to review the retention criteria.

Conditions of Storage

The minimum conditions for all core and sample storage at all stages are:

1. Positive protection against wetting and drying but not against temperature changes. (Cores secured for labo-

ratory test purposes that might be damaged through loss of moisture or freezing should be given appropriate protection).

2. Protection against access, damage, pillage by unauthorized individuals and snake or rodent infestation.

3. Core boxes and samples should be systematically grouped by drill hole number, investigation site, and project, and stacked to permit reasonably easy access and examination of the core and samples from individual holes without excessive unstacking and moving of adjacent core boxes and samples. Height of core box or sample stacks should be consistent with safety regulations and reasonable ease of handling. Core box racks should be provided only when repeated reexamination and study are anticipated and when the time saved by having the boxes separated in units of four or five boxes would be commensurate with the cost of the racks.

4. Adequate records which include copies of final logs, photographs, and inventory of the core and samples stored at each core and sample storage location must be maintained by the office responsible for that storage facility. The records must include name of the feature or investigation site, drill hole number, and number of boxes and samples—whether they have been tested or not. The Regional Director's Office should maintain a list of the structure or investigation sites for which core is stored at each of the core storage facilities within that region.

Length of Storage

Proposed Structures or Projects

All core and samples secured during site investigations must be retained until the proposed structure(s), unit, or project is built and has performed satisfactory or was abandoned by reason of alternate construction or for other reasons with no reasonable chance that the proposed structure(s) will be revived for future consideration. The following are exceptions:

1. Appraisal.—At the termination of reconnaissance stage investigations, such as abandonment of proposed structure site(s) or completion of reconnaissance designs and estimates, the Regional Director should dispose of foundation core and samples and all disturbed soil samples secured in borrow pit investigations for dams, canals, etc. He may delay the proposal in special cases for a definite period of time. Approval of the ACER for disposal or extended retention of appraisal stage core and soil samples is not required.

2. Feasibility—Disturbed soil samples from borrow pit investigations secured during feasibility stage investigations and not used for testing should be discarded at the termination of the investigation stage as manifested by the approval of the project planning report, unless it is evident that interest in the project is sufficient to assure its continuing development. If, at the end of one year, further development work has not materialized, the collected samples should be discarded on the presumption that deterioration has been sufficient to make further tests on such samples unreliable.

Undisturbed soil samples retained on the project can, in all cases, be discarded one year after collection, if not tested by then.

Specifications Design Investigations and Completed Structures or Projects

Requirements for length of storage for various types of samples and core are as follows:

(1) Borrow pit investigations for design.—Borrow pit soil samples collected for investigations leading to construction should be retained until construction is completed, as evidenced by a contract release except as they are consumed in routine testing. The Principal Designer should be notified of any pending disposal so that any needed samples can be retained.

(2) Borrow pit investigations for construction control.—Borrow pit soil samples collected for construction control

investigations and field laboratory testing should be discarded after completion of the field laboratory testing except when future use is anticipated.

(3) Record samples from fill.—Samples collected for record tests, not consumed in record testing, should be transmitted to the Denver Office for retention unless is appears that the magnitude of the collection is greater than necessary for effective representation of the materials used for construction. Such occasions are rare and should be handled as special problems through communication with the Division of Research and Laboratory Services, Denver, and the Principal Designer.

(4) Foundation core and samples.—All foundation core and samples secured during construction and prior investigation and not consumed in testing may be disposed of when all of the following requirements have been met:

(a) A minimum period of trouble-free operation has passed. The following criteria should be followed in determining the length of a trouble-free operation period:

- One year.—Canals and distribution systems including pipelines, minor or small engineering structures, low dikes or embankments, provided no claims are pending.
- Five years.—Large or major engineering structures such as dams, power or pumping plants, main feeder canals, main power conduits. For large dams, the 5-year time period should begin after complete reservoir filling. Retain the core and samples from a few representative drill holes for the life of the engineering structure.

(b) Completion of all contractual negotiations and settlement of claims which might involve reinspection or testing of the core or samples.

(c) Completion of initial SEED analysis, Modification Decision Analysis, and Modification Construction Activities.

(d) Expiration of all special agreements or guarantees made by Reclamation with other agencies for the maintenance or performance of Reclamation structures which might involve reinspection of core and samples from foundations.

Disposal of Core and Samples

The retention of an adequate log or description and photographs of the core and samples are basic prerequisites to initiating the disposal procedures outlined below.

When the minimum retention periods and other requirements outlined above have been met, the Regional Director will inform the ACER and request authority to dispose of the core and samples or, if necessary, will recommend continued retention. (This requirement is not applicable to appraisal stage core and samples, Length of Storage).

The Denver Office will review the known and foreseeable requirements for the core or samples and take appropriate action. Such action normally will authorize the Regional Director to:

1. Dispose of all the core and samples.

2. Dispose of all the core and samples except for selected core samples as discussed under Retention of Rock Core and Samples.

3. Retain the core and samples in storage for a longer period if warranted by foundation behavior or related incomplete technical studies of the foundation and the engineering structure.

After disposal of the core and samples is authorized and any necessary rock core samples have been secured for Reclamation's use, the Regional Director is to comply with the requirements of any existing State or municipal laws or regulations affecting the region for disposition of the core, representative samples, or hole location data. The Regional Director will make the necessary arrangements to assure he is made aware of any such State, municipal, or local laws when enacted.

The Regional Director should consider the desirability of affording the State Geologist's Office, technical schools, colleges, museums, or similar groups in the general area that may be interested in geologic conditions, the opportunity to select and retain the cores before disposal.

If Government right-of-way near a constructed facility is available, a recommended disposal procedure is to place permanent markers in the core boxes, wrap the boxes in plastic, and bury the boxes in a marked location.

Retention of Rock Core and Samples

The authorization of the ACER for disposal of rock core and selected soil samples for a specific structure, group of structures, or project will sometimes include a request that the rock core from a few selected drill holes be retained. Geologic assistance to select the rock core retained should be provided by the Regional or Project Office as appropriate.

One phase of the Reclamation's foundation research includes the compilation of physical properties, stress-strain, and petrographic data on a range of rock types for correlation and use in preliminary design and estimating studies. Samples for that purpose are tested as time permits and are to be secured only when specifically requested by the ACER. When requested, such sample sets will consist of about 20 linear feet of N-size core from each of the major rock types at the site. The length of the individual pieces of rock core should be at least twice the core diameter and selected to avoid pieces with incipient fractures. Each piece must be identified by drill hole number and depth and packed to prevent breakage in shipment.

Boxing and Labeling Drill Core for Storage

Specific requirements for the care of core are provided in Chapters 9 and 12. However, the following general comments are provided. To facilitate storage, handling, and easy installation of contents, standard core box sizes and labeling procedures should be adopted. Core boxes should be constructed at the lowest cost consistent with providing a sturdy box capable of withstanding a reasonable amount of careful handling, stacking, and shipment when filled with rock core.

As a minimum, each box should be properly labeled. To facilitate identification when stacked, this information should be shown on one end and the top of each core box. Temporary labeling used while drilling a hole must be replaced with permanent labeling which will remain legible after handling, stacking, or storing for long periods. A drawing or an index file should be maintained which shows the location of drill holes by stacks or shelves in a large or congested storage area so that individual boxes can be retrieved with minimal effort.

Chapter 16
REMOTE SENSING TECHNIQUES

Introduction

This chapter briefly summarizes the capabilities, limitations and requirements of various remote sensing techniques. The engineering geologist is encouraged to seek assistance from appropriate specialists to evaluate situations, solve problems, and achieve goals.

Remote sensing is a broad subject, but this discussion is limited to remote imaging. Geologic interpretation of remotely sensed data may be simple or complicated, depending on the nature of the data and the objective of the study. Remote sensing is a tool which makes some tasks easier, and enables some tasks that could not otherwise be accomplished, but is inappropriate for others. Depending on the individual situation, remote sensing may be extremely valuable or totally useless. Some remote sensing interpretations can stand on their own with confidence, but for most it is essential to perform related ground-truth work to establish reliability.

Imaging Systems

There are three main types of imaging systems, two of which are widely used in terrestrial applications.

Photographic.—Cameras and film are used. Photography provides the best spatial resolution, but less flexibility in spectral data collection and image enhancement.

Digital.—Electronic sensors are used, usually scanners which have less spatial resolution than photographs but can gather a variety of spectral data and enable a wide variety of image processing and enhancement techniques.

Vidicon.—A television type system is used. Vidicon systems generally are inferior to other types both spatially and spectrally. They are used mostly on space probes because of operational constraints.

Resolution

Spatial.—The sharpness of an image and the minimun size of objects that can be distinguished in the image are a function of spatial resolution.

Spectral.—The width of the part of the electromagnetic spectrum imaged defines spectral resolution. The electromagnetic spectrum is an ordered array of electromagnetic radiation based on wavelength. Certain portions of the electromagnetic spectrum, including the visible, reflective infrared, thermal infrared and microwave bands, are useful for remote sensing applications. Materials have spectral signatures, distinctive absorptive and reflective spectral characteristics, which allow them to be recognized. Given sufficient multispectral data, digital image processing generally will enable unique spectral signatures to be identified. In practice, instrumental limitations, or cost limits on computer processing, may preclude the unambiguous identification of some materials.

Photography

General.—The uses of aerial photography in engineering geology are discussed in Chapter 6. A brief description of types is given here.

Panchromatic (black and white).—Panchromatic photography records images essentially across the entire visible spectrum, and with proper film and filters also can record into the near-infrared. In aerial photography, blue generally is filtered out to reduce the effects of atmospheric haze.

Natural color.—Images are recorded in the natural colors seen by the human eye in the visible portion of the spectrum.

False-color infrared.—Images are recorded using part of the visible spectrum and part of the near-infrared, but the colors in the resultant photographs are arbitrary and not natural. Infrared film commonly is used and is less affected by haze than other types.

Multispectral.—Photographs acquired by multiple cameras simultaneously recording different portions of the spectrum can ease interpretation.

Thermal Infrared Imagery

Thermal infrared systems create images by scanning and recording radiant temperatures of surfaces. Some characteristics of thermal image data are generic to digital image data, enabling computer image processing, and others are unique to thermal infrared images, making them valuable interpretive tools.

Thermal infrared imagery can be interpreted using conventional photogeologic techniques in conjunction with knowledge of the thermal properties of materials and instrumental and environmental factors that affect the data. Where thermal characteristics of a material are unique, thermal infrared imagery can be easy to interpret and can be a great help in geologic studies. However, thermal characteristics of a material can vary with moisture content, differential solar heating, and topography, and this can make interpretation more difficult and ambiguous.

MSS (Multispectral Scanner) Imagery

MSS images are a series of images of the same target, acquired simultaneously in different parts of the electromagnetic spectrum. MSS images are an array of lines of sequentially scanned digital data, as opposed to the simultaneously exposed area of a photograph. They may have unique distortions and may or may not have high resolution and/or information content. Scanner systems consist of scanning mechanisms, spectral separators, detectors, and data recorders.

Because a digital image is actually an array of numerical data, it can be manipulated by a computer for a variety of purposes. Geometric distortions caused by sensor characteristics can be removed, or distortions can be introduced if desired. Computer processing can be used to precisely register a digital image to a map or another image. Various techniques can be used to improve image quality and/or interpretability. Various types of data, for example thermal and visible imagery, or a digital image and digitized gravity data, can be merged into a single image. Subtle information, difficult to interpret or even to detect, can sometimes be extracted from an image by digital processing.

Airborne MSS Imagery

Image characteristics.—A number of different airborne MSS systems are available, with various spatial and spectral characteristics. Some systems are capable of recording ten or more spectral bands simultaneously, ranging from ultraviolet to thermal infrared. Typical digital image processing techniques are used. The size of data sets and the number of separate spectral bands on some airborne MSS systems may require data consolidation or careful selection of data subsets for special processing. Interpretation typically involves normal photogeologic techniques along with knowledge of spectral characteristics and the data manipulations applied.

Advantages and limitations.—High resolution can be obtained, and with proper band selection and processing, even geochemical information may be extractable from imagery. Depending on the complexity of the geology and the size of the area studied, however, the necessary digital processing may become very expensive and might require much experimentation to obtain satisfactory results.

Satellite MSS Imagery

Landsat is the U. S. satellite for civilian remote sensing of the Earth's land surface. The Landsat MSS (multispectral scanner) records four bands at 80-meter resolution. Though primarily oriented toward agricultural applications, it has proven useful for some geological applications. The current Landsat is equipped also with a TM (thematic mapper), which has increased spatial and spectral resolution compared to the MSS. The TM records seven bands at 30-meter resolution and is much more useful for geology.

A French satellite, SPOT, provides panchromatic imagery with up to 10-meter spatial resolution and MSS imagery at 20-meter resolution. It is capable of stereo imaging.

Satellite imagery provides a synoptic view of a large area, which is valuable for regional studies, but the limited resolutions currently available restrict its value for engineering geology.

Radar Imagery

Radar is an active remote sensing method (as opposed to passive methods like photography and thermal infrared) and is independent of lighting conditions and cloudiness. Some satellite radar imagery is available, but like Landsat, it is more useful for regional geologic studies than for engineering geology. SLAR (side-looking airborne radar) produces a radar image of the terrain on one side of the airplane carrying it (equivalent to a low-oblique airphoto).

Image characteristics.—Radar imagery has some unusual distortions which require care in interpretation. Resolution is affected by several factors, and the reflectivity of target materials must be considered. The analysis and interpretation of radar imagery requires knowledge of the imaging system, look direction, and the responses of the target materials.

Advantages and disadvantages.—Radar can penetrate clouds and darkness, and to some extent, vegetation or even soil. Distortions, image geometry and resolution can complicate interpretation, as can a lack of multispectral information.

Applications to Engineering Geology

The most useful form of remote sensing for engineering geology in general is aerial photography, because of its high resolution, high information content and low cost. Various scales of airphotos are valuable for regional studies and site studies, for both detection and mapping of a wide variety of geologic features of importance to engineering geology.

Applications of other forms of remote sensing to engineering geology depend on the nature of the problem to be solved and the characteristics of the site geology. Some problems can best be solved using remote sensing, and for others, remote sensing is of no value. In some cases, the only way to find out if remote sensing can do the job is to try it.

Availability of Imagery

The entire conterminous United States has been imaged by the Landsat MSS. Partial Landsat TM and SPOT coverage of the U. S. are also available. SLAR coverage of about 25% of the U. S. is available as of 1987. Other types of imagery are available, but generally only for limited areas. The Remote Sensing Section, Code D-3744, Denver Office, has a large number of Landsat images of the western U.S. available for USBR use, along with a limited amount of thermal infrared and airborne MSS images of some USBR project areas. The Remote Sensing Section should be contacted first to determine whether Reclamation already has the imagery desired. If, not, the section can assist in determining availability and in acquisition of imagery, or may direct you to other sources of help.

Mission Planning

Numerous factors make planning a remote sensing mission more complicated than planning for a conventional aerial photographic mission. Remote sensing mission planning should be done by, or in consultation with, an expert in the field.

Time and Cost Estimating

The cost of data acquisition is relatively easy to estimate. The cost of interpretation is a function of the time and image processing required and is much harder to estimate. Some forms of data are inexpensive to acquire and require little processing to be useful. Other forms may be expensive to acquire, and/or may require much processing, perhaps needing experimentation to determine what will work in an untried situation. In such a case, the cost may be greater than the benefits.

Technical Assistance

The staff of the Remote Sensing Section, Code D-3744, Denver Office, is comprised of remote sensing specialists. They can provide technical assistance to decide whether remote sensing is applicable to a specific task, to acquire existing imagery, to plan a mission if no imagery is available, and provide a cost estimate. The Remote Sensing Section maintains an in-house computer capable of a full range of digital image processing and can generate hard copies of images. They can provide raw or processed images for the geologist to interpret, can assist the geologist in interpretation, or can carry out the interpretation.

BIBLIOGRAPHY

Two excellent reference books dealing with remote sensing and applications to geology are:

Sabins, F. F., *Remote sensing—principles and interpretation*, 2nd edition: Freeman, New York, NY, 449p, 1987.

Siegal, B. S., and Gillespie, A. R., eds., *Remote Sensing in geology*, Wiley & Sons, New York, NY, 702p, 1980.

For a thorough treatment of remote sensing ("more than you ever wanted to know about remote sensing"), including a 287-page chapter on geological applications with abundant color images, see:

Colwell, R. N., ed., *Manual of remote sensing*, 2nd edition, Falls Church, VA, American Society of Photogrammetry, 2724p, 1983.

Chapter 17
CONSTRUCTION DEWATERING

Dewatering is defined as the removal of ground water and/or seepage from below the surface of the ground or other constructed surfaces, and the control of such water. **Unwatering**, as defined in Reclamation Construction specifications, is the removal of ponded or flowing surface water from within cofferdams, excavations, channels, ditches, or sumps, and the control of such water.

Activities involving excavation of materials or construction near or below the water table, under artesian conditions, or near surface water bodies usually require control of the ground water and/or seepage. Such control may involve removal of the water by dewatering or unwatering, isolation by cutoffs, stabilization by freezing or other methods, or a combination of these methods. Control of ground water and seepage usually involves installation and operation of wells, well points, or drains. A key operation in most dewatering in unstable materials is the removal of water from below the ground surface in advance of the excavation and maintaining the water level at a suitable distance below the working surface. This permits construction activities to continue unhampered by the presence or adverse effects of water.

In some excavations such as those in rock, cemented granular materials, clays, and other stable materials, it may be possible to dewater by draining water to sumps and removing it using surface mounted pumps concurrently with or following completion of the excavation (referred to as unwatering).

Subsurface cutoffs, such as a sheet piling and slurry walls in unstable materials and grouting in rock, also are used at times to control ground water, as well as for surface water control and ground support.

However, such cutoffs are seldom 100 percent effective; therefore, supplementary dewatering is usually required.

Dewatering usually is performed in conjunction with unwatering to assure control of surface water and to permit dewatering to proceed unaffected by possible recharge or flooding from nearby surface water bodies.

Failure to properly remove and/or control water during unwatering or dewatering may have serious consequences including:

1. Unstable natural or excavated slopes;
2. Unstable, unworkable or unsuitable subgrade;
3. Boils, springs, blowouts, or seeps on slopes or in the subgrade;
4. Flooding of excavations or subsurface structures;
5. Uplift beneath and disturbance of constructed features such as concrete slabs;
6. Dilution, corrosion or other adverse effects on concrete, metals or other construction materials;
7. Threat to the stability of nearby structures;
8. Threat to surrounding surface water and groundwater levels and availability;
9. Instability of cutoff facilities such as cofferdams;
10. Loss of fines from the foundation;
11. Threat to life and property;
12. Construction delays; and
13. Increased construction costs.

This chapter will acquaint the engineering geologist with the background and basic requirements for construction dewatering and will aid the recognition of site conditions that need dewatering and the extent thereof.

A more comprehensive discussion of technical requirements and methods for construction dewatering is available in the Bureau of Reclamation's *Ground Water Manual*.

Scope

This chapter includes the scope of all activities associated with dewatering in which an engineering geologist would be involved by virtue and nature of the work, technical expertise, organizational position or delegated responsibilities.

Included activities are:

1. Site review;
2. Site investigations;
3. Data collection;
4. Data interpretation, evaluation, and presentation;
5. Compiling specifications paragraphs;
6. Construction considerations;
7. Supervision/overview of operations;
9. Monitoring of operations;
10. Evaluation of operations; and
11. Documentation of results (final construction report).

Responsibility and Role of the Engineering Geologist

Geologists have an essential and continuing responsibility and role in dewatering beginning with initial site inspection, selection, and evaluation and this role extends through completion of construction and documentation of activities and results. The geologist's role stems from the nature of dewatering which primarily is a subsurface activity over which geologists normally have significant if not principal technical and organizational responsibility.

Typical areas of responsibility include:

1. Selecting, inspecting and evaluating the site—Principal Geologist, Regional Geologist, Project Geologist;

2. Preparing site investigations and data collection program and coordinating with other activities—Principal Geologist, Regional Geologist, Project Geologist;

3. Conducting site investigations and collecting and assembling data—Project Geologist;

4. Evaluating data—Regional Geologist, Principal Geologist, Project Geologist;

5. Preparing specifications, designs, drawings, construction considerations—Principal Geologist;

6. Coordinating dewatering activities with other design and construction activities—Principal Geologist, Project Geologist;

7. Reviewing Contractor's proposed dewatering plans and other associated documents—Project Geologist, Principal Geologist;

8. Supervising and/or overseeing installation of dewatering facilities operations—Project Geologist;

9. Monitoring and/or supervising the monitoring of dewatering operations—Project Geologist;

10. Evaluating the suitability and adequacy of dewatering operations—Project Geologist, Principal Geologist;

11. Supervising and/or overseeing the removal, abandonment and sealing of dewatering facilities—Project Geologist; and

12. Preparing and assembling the dewatering section for the Final Geology Report—Project Geologist.

It may become necessary, because of specialized technical nature of dewatering activities, to provide individual geologists with additional training in this field. Technical assistance also may be provided by a Dewatering Specialist.

Recognition of Problem Areas

The dewatering task may vary widely in scope, magnitude, and technical difficulty. Some controlling factors are related to the constructed feature and include areal extent, foundation depth, and construction time. Other factors are related to site conditions such as:

1. Subsurface geology including general material types, layering and thicknesses, attitudes of layers, lateral extent and continuity.

2. Subsurface hydraulic conditions including permeabilities and thicknesses of different materials, ground-water occurrences and levels.

3. Recharge conditions including proximity to surface water bodies, and precipitation.

4. Other construction facilities including cofferdams and site access.

Conditions that should alert a geologist to the need for dewatering and the potential for difficult dewatering operations or specific problem areas include:

1. Site location adjacent to a major surface water body, a stream, marshy area, or an area subject to flooding.

2. An excavation significantly below the water table.

3. Complex foundation geology.

4. An artesian zone immediately below subgrade with artesian heads above subgrade.

5. Existing structures or facilities in the immediate area.

6. Existing use of ground water in the immediate or surrounding area.

7. Anticipated poor quality ground water in the immediate or surrounding area.

7. Anticipated poor quality ground water or the presence of hazarouds gases such as methane or hydrogen sulfide.

8. Thick zones of saturated, low strength materials such as silt or soft clay, especially under artesian conditions.

9. Presence of cofferdams or other similar features for which dewatering is needed for stability.

10. Conditions in which the lack of or the failure of dewatering facilites could result in catastrophic failure of protective or other features with subsequent hazard to life or property.

It is essential that construction sites that require control of ground water and/or seepage for construction or proper operation of a facility be identified as early in the planning or design process as possible.

Exploration Program Input

Where feasible to do so, investigations for dewatering should be incorporated into and coordinated with the general exploration and design data collection program for the feature to be constructed. This has a number of advantages including:

1. Maximizing the use of drilling and other similar activities, thereby lowering overall exploration costs.

2. Providing dewatering data early in the program.

3. Coordinating dewatering requirements with other investigations requirements.

4. Using field personnel for a variety of investigations requirements, thereby maximizing efficiency and professional development.

An attempt should be made to recognize problems early and incorporate solutions into the program.

Generally, a dewatering investigations program cannot be established in detail until some reconnaissance level drilling has been done and general subsurface geologic and hydrologic conditions are determined. In addition, general surface conditions including topography and surface hydrology should be known. Also, the dewatering specialist should be consulted as early in the program as possible in order to assure full coordination and the maximum benefits of obtained data.

Design Data Requirements, Responsibilities, and Methods of Collection and Presentation

Adequate and appropriate surface and subsurface data are essential to the proper design, installation and operation of dewatering facilities. The type, extent, and completeness, of the data are directly related to the site conditions, size and complexity of the features required construction time and other similar factors. In some instances, the amount of data required for a dewatering facilities design, may equal or exceed the foundation data required for design of the constructed feature.

Reclamation practice varies in assigning responsibility for design of dewatering facilities. Responsibility for the design of dewatering facilities, as well as installation and operation generally lie with the Contractor. However, Reclamation may retain responsibility for design of such facilities where dewatering is expected to be especially complex, difficult, risky, or for which there are other overriding considerations.

Regardless of the assignment of responsibility the collection of field data are necessary to the proper design of dewatering facilities. As noted previously, investigations to obtain such data may be extensive, complex and time consuming, and beyond the capability of a contractor in the normal bidding period of 30 to 45 days. In addition, the Contractor may not have the time to perform an extensive evaluation of data required to arrive at an assessment of the need for, design of, and cost of dewatering facilities.

In view of these factors, adequate and appropriate data for design of dewatering facilities should be obtained regardless of who has ultimate responsibility for the design of such facilities. The extent and level of data should commensurate with the anticipated dewatering requirements and dewatering facilities. For example, if pumping tests are required, the test wells should approach the size and capacity of anticipated dewatering wells. If appropriate, such facilities should be preserved and made available to prospective Contractors for their testing and/or operational use.

If the Contractor is responsible for design, complete field data should be included in the construction specifications. Such data includes all pertinent results, including details of drilling and completion of wells, piezometer installation, and other installations as well as summarized test data. However, data should be as concise as possible and clearly referenced as to history, sequence, site locations, and other factors.

Design data for dewatering facilities should be obtained concurrently with and in coordination with design data for the feature to be constructed if possible. Reclamation dewatering specialists should be consulted for input when preparing a design data program, especially such activities as foundation drilling and water/pump testing.

Dewatering data are an integral and essential part of the design data package and must be given the required priority in funds, time and personnel to minimize possible problems such as construction delays and claims.

In some instances, where dewatering may have impacts of existing adjacent structures, facilities or water resources, a study of the area surrounding the site may be necessary to determine and document impacts as an integral part of data gathering.

In addition to data involving the constructed feature such as plan layout, excavation depth, and time to construct, other data are required on site conditions such as:

1. Surface

a. Site and surrounding topography at an appropriate scale and contour interval

b. Cultural features on and off site

c. Site and surrounding surface geology with descriptions of materials

d. Site and adjacent surface water features such as lakes, streams, wetlands

Surface information shall include data that might reflect favorable or unfavorably as to soil erosion or resistance or how it relates to runoff or to a potential recharge of the ground-water system.

e. Plan map of all data points including locations of drill holes, test holes, piezometers, observation wells, and test wells, overlays on the plan of the proposed feature.

2. Subsurface.—Subsurface information shall include data that provide a lead to representative hydraulic conductivities areal distribution of relative conductivities, location and strength of potential recharge sources and/or barriers and anticipated seasonal changes in the ground-water system. More specific data that provides this information include:

a. General geology of the site and surrounding area including geologic cross sections that show vertical and lateral variations in materials encountered in drill holes.

b. Logs of drill holes, test, holes, and piezometers with depths and thickness of materials, description of materials, and results of testing.

c. Results of material sampling including depths, descriptions, mechanical analyses, and hydrometer analyses.

d. Geophysical logs where appropriate.

e. Pumping and other similar test results including layout of test holes, depths and design of wells and piezometers, tabulated test results including yields and drawdown with time, and static water levels.

f. Water quality analyses.

3. Other

a. Climatic data including temperature, and precipitation, on a daily or other appropriate basis for the nearest station for the period of record. Also, details where appropriate on the occurrence of severe storms; other similar events.

b. Where appropriate, stream flow and elevation, lake or reservoir elevation and other similar data for the period of record.

c. Ground-water levels for monitored observation wells, piezometers, test wells, drill holes, and pits, for the periods of record.

d. Where there is evidence of a hydraulic connection between a nearby surface water body and the ground water, continuous monitoring of both features for a typical hydrologic cycle is required.

Presentation of Data.—The presentation of data for dewatering use may differ from that used to portray conventional geologic data because of several factors:

1. Dewatering data are subject to quantitative interpretation which may vary widely among different specialists.

2. Conditions such as water levels, flow and water quality vary with time.

3. Conditions, such as water levels in a foundation and an adjacent river, are related in time and space.

Because of the potential problems of conflicting interpretations, most dewatering data such as those from pumping tests, and packer tests, should be presented as observed, field data without interpretation. However, a full description of the site, subsurface conditions, and test facilities should be given along with such data (fig. 17–1 and 17–2).

Where time and/or time and space related data are presented, every effort should be made to present these in a manner that will assure maximum recognition and proper interpretation. For example hydrographs which plot time versus water levels, are especially useful.

However, if the design of the facilities is assigned to the Contractor under performance-type specifications, the requirements and detail of the considerations may be reduced to compensate for the reduced responsibility by the Reclamation.

The Role of the Geologist During Construction Dewatering

For construction activities involving dewatering, the project geologist has a crucial role in coordination between the design and construction personnel. He/she must determine that the dewatering is being accomplished in accordance with the specifications and construction considerations. In addition, the project geologist must be assured that the dewatering system is performing satisfactorily and in a manner consistent with site condition. As the principal project geological and geotechnical specialist, the geologist's role is paramount in the area of the strongly geology-related dewatering responsibilities.

The geologist's role during construction includes a number of specific tasks that extend throughout the construction period and include:

1. Reviewing general dewatering requirements, system needs, operational criteria and other features in advance of construction.

2. Reviewing the Contractor's proposed dewatering plan.

3. Overseeing and documenting installation of dewatering and monitoring facilities.

4. Overseeing monitoring of dewatering operations and collection of data.

5. Evaluating the performance and adequacy of the dewatering system including routine and non-routine operations.

6. Overseeing the removal, abandonment and sealing of dewatering and monitoring facilities.

7. Documenting the dewatering experiences and results

Monitoring

Dewatering activities and related influences and impacts must be monitored during construction and in some cases up to a year or more before start of, and following completion of construction. Details of the monitoring program including design and layout of the system, the responsibilities for installing the system physically conducting the monitoring and maintaining records must be included in the specifications and construction considerations to assure an adequate level of reliable data and alert Reclamation construction personnel and the Contractor to the monitoring requirements.

Such monitoring is intended to:

1. Provide data on base level conditions.

2. Confirm that the requirements of the specifications are being met.

3. Maintain a general data base on conditions and impact resulting from the dewatering.

4. Alert personnel to unsuitable, hazardous or potentially hazardous conditions.

5. Document conditions in the event of claims or litigation.

Figure 17 [illegible]

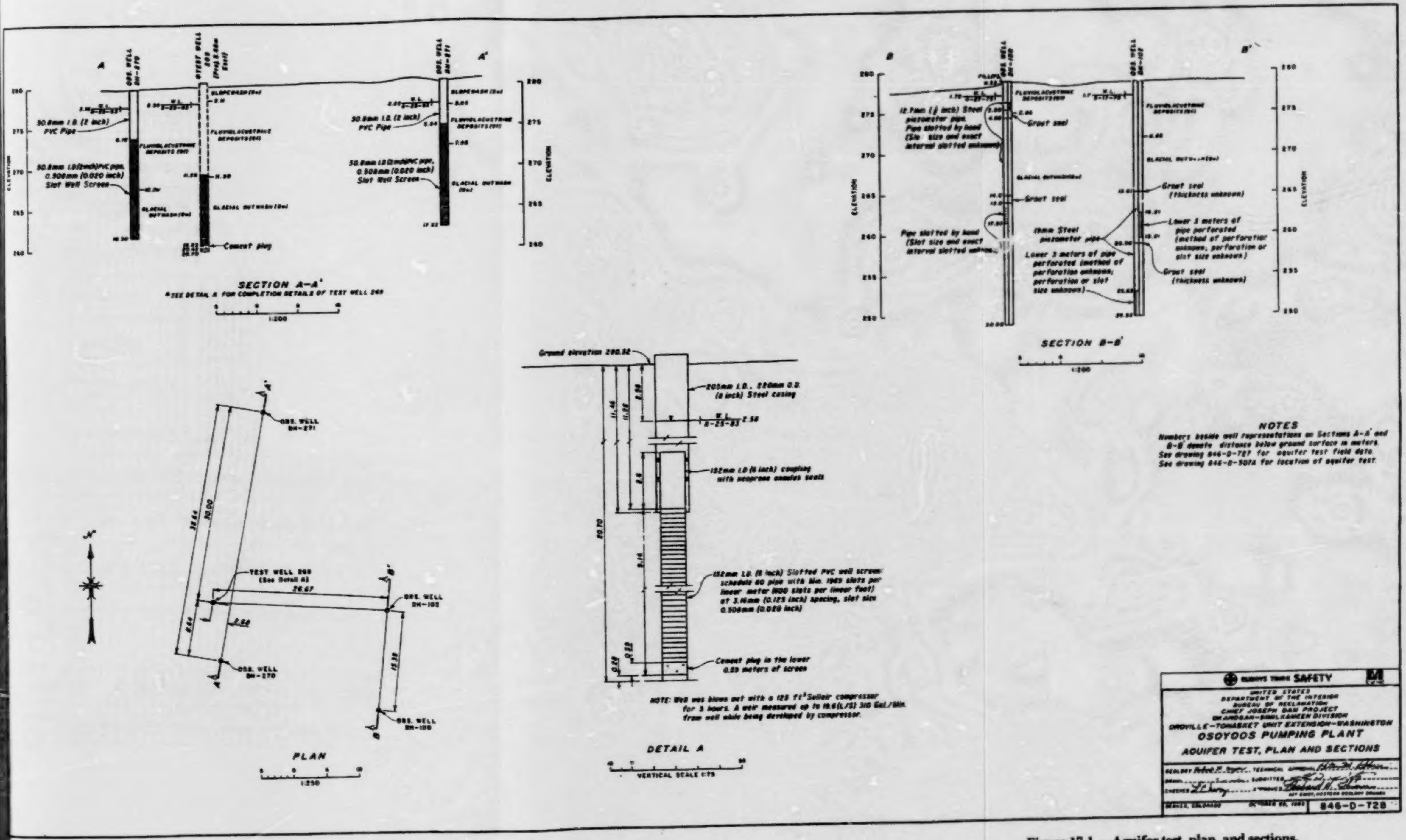

A
OBS. WELL BH-270
TEST WELL 269
A'
OBS. WELL BH-271
50.8mm I.D. (2 inch) PVC Pipe
50.8mm I.D.(2inch)PVC pipe, 0.508mm (0.020 inch) Slot Well Screen
SLOPEWASH (Sw)
FLUVIOLACUSTRINE DEPOSITS (Dl)
GLACIAL OUTWASH (Ow)
W.L.
Cement plug
ELEVATION
280
275
270
265
260
SECTION A-A'
*SEE DETAIL A FOR COMPLETION DETAILS OF TEST WELL 269
1:200
B
B'
OBS. WELL BH-100
OBS. WELL BH-102
12.7mm (½ inch) Steel piezometer pipe. Pipe slotted by hand (Slot size and exact interval slotted unknown)
Grout seal
Pipe slotted by hand (Slot size and exact interval slotted unknown)
18mm Steel piezometer pipe
Lower 3 meters of pipe perforated (method of perforation unknown; perforation or slot size unknown)
Grout seal (thickness unknown)
Lower 3 meters of pipe perforated (method of perforation unknown, perforation or slot size unknown)
Grout seal (thickness unknown)
SECTION B-B'
1:200
Ground elevation 280.32
203mm I.D., 220mm O.D. (8 inch) Steel casing
W.L. 8-25-83 2.58
152mm I.D (6 inch) coupling with neoprene annulus seals
152mm I.D. (6 inch) Slotted PVC well screen: schedule 60 pipe with Min. 1969 slots per linear meter (600 slots per linear foot) at 3.16mm (0.125 inch) spacing, slot size 0.508mm (0.020 inch)
Cement plug in the lower 0.59 meters of screen
20.70
NOTE: Well was blown out with a 125 ft³ Sullair compressor for 3 hours. A weir measured up to 19.6(L/S) 310 Gal./Min. from well while being developed by compressor.
DETAIL A
VERTICAL SCALE 1:75
N
OBS. WELL BH-271
TEST WELL 269 (See Detail A)
26.67
OBS. WELL BH-102
OBS. WELL BH-270
OBS. WELL BH-100
38.64
30.00
8.64
2.60
15.38
PLAN
1:250
NOTES
Numbers beside well representations on Sections A-A' and B-B' denote distance below ground surface in meters.
See drawing 846-D-727 for aquifer test field data.
See drawing 846-D-507A for location of aquifer test.
ALWAYS THINK SAFETY
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CHIEF JOSEPH DAM PROJECT
OKANOGAN-SIMILKAMEEN DIVISION
OROVILLE-TONASKET UNIT EXTENSION-WASHINGTON
OSOYOOS PUMPING PLANT
AQUIFER TEST, PLAN AND SECTIONS
GEOLOGY
TECHNICAL APPROVAL
DRAWN
SUBMITTED
CHECKED
APPROVED
DENVER, COLORADO
OCTOBER 20, 1983
846-D-728

Figure 17-1. – Aquifer test, plan, and sections.

PUMPED WELL WELL NO. 269			OBSERVATION WELL DH-270 RADIUS 30 FEET		OBSERVATION WELL DH-271 RADIUS 99 FEET		OBSERVATION WELL DH-100 RADIUS 100 FEET				OBSERVATION WELL DH-102 RADIUS 87 FEET			
							DEEP PIEZOMETER *		SHALLOW PIEZOMETER		DEEP PIEZOMETER		SHALLOW PIEZOMETER	
ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)	DISCHARGE (GAL./MIN.)	ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)	ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)	ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)	ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)	ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)	ELAPSED TIME (MINUTES)	DRAWDOWN (FEET)
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.17	0.93	-	1	0.07	1	0	41	+0.57	41	0.13	36	0.03	36	0.25
0.50	1.02	-	1.5	0.09	2	0.05	63	+1.09	315	0.11	83	0.03	84	0.22
0.67	1.03	-	4	0.10	3	0.05	151	+1.36	379	0.18	146	0.04	147	0.24
0.83	1.07	-	5	0.07	4	0.05	194	+1.37	441	0.19	201	0.05	202	0.24
1	1.09	-	8	0.11	5	0.05	314	+1.42	496	0.16	311	0.10	312	0.38
1.17	1.12	-	10	0.11	7	0.05	378	+1.33	619	0.20	377	0.04	377	0.38
1.33	1.13	170	14	0.11	9	0.05	441	+1.36	731	0.27	402	0.06	402	0.30
1.67	1.05	-	21	0.11*	11	0.05	496	+1.38	859	0.19	438	0.08	439	0.15
1.83	1.01	-	31	0.12	13	0.09	620	+1.33	*976	0.21	491	0.09	491	0.36
2	1.03	-	40	0.11*	15	0.09	731	+1.34			617	0.16	617	0.37
2.33	1.11	-	48	0.13	20	0.09	830	+1.34			738	0.17	739	0.38
2.67	1.10	-	53	0.13	25	0.09	976	+1.43			855	0.11	856	0.36
3	1.08	-	58	0.14	30	0.09	1089	+1.50			979	0.12	979	0.36
3.50	1.09	-	73	0.14*	35	0.09			(Obstruction noted at 5.35 feet)		1098	0.15	1099	0.35
4	1.11	-	85	0.15	55	0.15								
5	1.10	170	97	0.16	65	0.10								
6	1.10	-	103	0.17	75	0.15								
7	1.11	-	119	0.19	85	0.15								
8	1.11	-	138	0.20	95	0.15								
9	1.11	-	168	0.18	105	0.15								
10	1.11	175*	171	0.17	123	0.15								
12	1.12	-	183	0.19	138	0.15								
14	1.11	-	231	0.19	153	0.15								
16	1.15	-	250	0.19	168	0.15								
18	1.15	-	265	0.16	183	0.15								
20	1.14	-	318	0.18	198	0.15								
25	1.15	-	378	0.21	213	0.15								
30	1.14	175*	433	0.21	228	0.15								
35	1.15	-	498	0.22	243	0.15								
40	1.13	-	618	0.24	258	0.15								
45	1.14	-	738	0.24	318	0.16								
50	1.15	-	858	0.25	378	0.10								
60	1.15	-	978	0.23	438	0.15								
70	1.17	-	1103	0.23	498	0.23								
80	1.18	-	1118	0.19	741	0.25								
90	1.17	-			853	0.25								
100	1.15	178			980	0.25								
120	1.15	180			1100	0.28								
135	1.15	-			1126	0.29								

* Apparently influenced by discharge water. One small part of flow ponds about 10 feet west of well, and then flows within 8 feet of the well as it flows past on the way to the lake.

* May have been responding. However readings believed to be unreliable. Due to obstruction in pipe and behavior of the deep piezometer. No further readings taken.

NOTE: Well located about 30 feet from lake shore

Figure 17-2. – Aquifer test data.

6. Provide background data for a followup analysis in the event of a slope, foundation or structural failure.

Monitoring Requirements.—Facilities should be required for the monitoring of dewatering activities and features such as:

1. Ground-water levels
2. Discharge from dewatering facilities
3. Sediment content of discharge
4. Chemical and biologic quality of water from dewatering facilities
5. Ground surface and structure elevations
6. Horizontal control on constructed features, and natural and excavated slopes
7. Levels of nearby surface water bodies
8. Stability of nearby structures

The monitoring facilities may range from a few observatio wells to a complex system involving sophisticated equipmen and continuous and possibly remote monitoring facilitie The extent, complexity and capability of facilities depend on the size, complexity, hydrologic and geologic condition excavation depths and other such factors of the job. Concer for hazard to life and property in the event on failure shoul be paramount.

Ground-water Monitoring.—Monitoring of ground-wate levels during construction should cover excavation, are surrounding the excavations, and off site locations. Excavations with any substantial width (other than trenches) an depth more than a few feet below the anticipated water leve should have ground-water monitoring instrumentation installed directly in the excavation. Excavations underlain a shallow depths by artesian conditions should be monitore similarly.

1. Ground-water Monitoring Locations.—Locations of ground-water monitoring instrumentation within an excavation may cause inconvenience for the Contractor during construction; however, the capability of monitoring ground-water levels within an excavation generally justifies such inconveniences. Since the most difficult area to dewater is usually the center of the excavation, ground-water monitoring instruments should be located near the center. Special provisions may have to be made to ensure continued ground-water monitoring of the facilities during all stages of the excavation. in some cases, the ground-water monitoring instrumentation, such as well standpipes or casings, are to be incorporated into the structure. This will require that the monitoring instrument be embedded in concrete, such as wall or pier to permit continuous monitoring, and simplify the backfill operations. Install a continuous, water-level monitoring instrument in the facilities to assure the maximum level of ground-water monitoring and control.

In areas surrounding the excavation, water level monitoring instrumentation should be located to provide monitoring of representative areas, and specific problem areas where needed.

Ground-water levels in off-site locations should be monitored to maintain a general record of conditions and document influences due to dewatering. Off-site monitoring is especially important in areas where ground water is widely used, where ground-water levels are crucial to existing activities, or where three might be other serious impacts such as subsidence, or ground-water level decline.

Locations of individual water level monitoring instrumentation must be based on conditions encountered at each site, layout of construction activities, layout of dewatering facilities and other similar factors. In most instances, monitoring instrumentation locations will have to be selected after other features such a dewatering systems, and roads have been located to avoid conflicts and ensure representative and reliable monitoring. However, it is essential to have instrumentation installed and be functioning long before construction in order to obtain trends and base level conditions. In some cases, existing instrumentation may be used for such monitoring. However, unless the construction and other details are well known, instrumentation designed specifically for the conditions of the site should be installed as a part of construction.

2. Ground-water Instrumentation.—Instrumentation for monitoring ground-water level usually consists of a system of observation wells and/or piezometers installed in the foundation and elsewhere on or off the site, depending on conditions.

The type of instrumentation, depth, diameter and other details, depend primarily on subsurface conditions, necessary operating life, type of monitoring and other factors. It is essential that the design of the instrumentation be tailored to the subsurface and other conditions of the site and that water levels observed in the instrumentation are a true indication of in-place conditions.

Observation wells, which are intended to monitor general ground-water level, can be used in areas where the foundation material is relatively uniform with depth, there is little or no layering and ground-water levels do not vary appreciably with depth. Piezometers should be used where layering exists, or perching, artesian or other complex conditions are expected.

Observation wells and piezometers usually consist of a section of well screen, perforated pipe or porous type set in the zone to be monitored and connected to a length of standpipe or casing extending to the surface. For piezometers, the section of well screen, perforations, or porous tube must be isolated at the top and bottom by grout or other sealant and a water tight standpipe must be used. The diameter of the screen and standpipe may range from a minimum of 1 inch (25 mm) up to 6 inch (150 mm) inside diameter depending on method of monitoring, and other factors. Water levels are measured directly in the well or piezometer by use of tape or electric sounder. Float-type recorders can be used to record continuous water level fluctuations but may require a minimum 4- to 6-inch diameter casing or standpipe. In addition, a wide range of electronic and pneumatic instruments is available for monitoring and recording ground-water levels.

Monitoring discharges from dewatering systems.—The discharge from dewatering facilities such as wells, well point systems, drains, and sump pumps, are to be monitored on a basis that provides a clear picture and permanent record of the operation of such equipment. Data to be reported shall include starting and stopping times, instantaneous rates of discharge, change in rates, and combined daily volumes.

Discharge rates are to be monitored by means of various flow meters (propeller, pitot tube, and acoustic), free discharge orifices, weirs, Parshall flumes, and volumetric (tank-stopwatch) methods. Meters must be calibrated using a volumetric test prior to flow testing. Measuring devices must be accurate within ± 10 percent.

1. Sediment content of discharge.—The sediment content of discharge from dewatering facilities including wells, well point systems, and drains are to be monitored to observe excessive sediment yield. Such sediment content can damage pumping equipment and cause deterioration of water quality in the receiving water body, and create voids in the foundation resulting in well collapse and foundation settlement.

Sediment content usually is measured in parts per million by volume of water take directly from the discharge. In a closed system this may require a spigot in the pipe. Measurement requires special equipment. If the limits are 50 parts per million or less, a special centrifugal measuring device is required. If the limits are more than 50 parts per million, an Imhoff cone can be used.

A discharge yielding excessive sediment is cause for concern. If sediment yield increases rapidly, the facility may require isolation and shut down to avoid serious damage.

2. Chemical and biologic quality of water.—The chemical and biologic quality of water discharged from de-

watering systems must be monitored by periodic collection and analysis of samples taken directly from the discharge of such systems. A single representative sample should be adequate if there are a number of discharges from the same source. However, if there is pumping from different sources, multiple samples may be needed. The initial samples are to be taken shortly after startup. The dewatering system (or during any test pumping done during exploration) and periodically thereafter during the operation. Each sample should have complete biologic and chemical analyses including those for heavy metals, organics, and pesticides. More frequent sampling and analyses is to be made to determine total dissolved solids, conductivity, and pH.

Monitoring Water Surfaces and Structures.—

1. Ground Surface Monitoring.—Ground surface and other pertinent points are to be monitored for settlement during dewatering activities. Use standard surveying methods (at least third order) and temporary benchmarks or other facilities as necessary to maintain vertical control.

Horizontal control is necessary in large and/or deep excavations which may be susceptible to slope failure. Where ground failure might endanger life and property, special instrumentation with alarm warning capability may be necessary.

2. Water Surface Monitoring.—Nearby surface water bodies, wetlands, drains and other similar features should be monitored where appropriate for level and discharge changes, and environmental deterioration.

3. Structural Monitoring.—Nearby structures that may be influenced by settlement or horizontal displacement due to ground-water withdrawal should be monitored. Both horizontal and vertical controls must be maintained to assure that movement can be measured and documented.

Performance Evaluation During Construction

The performance of the dewatering facilities is to be evaluated and documented periodically during construction. This will assure you that the requirements of the specifications are being met and that unusual or unexpected conditions are recorded and accommodated properly. Illustrative charts and diagrams such as water level hydrographs, plots of well or system discharge rates should be prepared at the start of dewatering operations and updated throughout the construction period. Such evaluation along with tables and graphs should be included in the monthly L-29's and will provide essential data to be included eventually in the Construction Geology Report. The evaluation should be coordinated with the design staff to assure a full and continuous understanding of conditions by all concerned.

Final Reporting

The Construction Geology Report shall include a section on dewatering, where applicable. This section presents a chronology of dewatering, and an evaluation of the performance of the facilities as well as the Contractor's compliance with the specifications. Problem areas and nonroutine events such as failures should be documented. Monitoring results including ground-water levels, and discharge rates should be presented in the form of hydrographs, and other similar plots or tabulated data.

Construction Dewatering Bibliography

[1] Cedergren, Harry R., *Seepage, Drainage and Flow Nets*, John Wiley and Sons, Inc., New York, NY 1967.

[2] Dewatering and Groundwater Control for Deep Excavations, TM5-818-5, NAVFAC P-418, AFM 88-5, Chapter 6, U.S. Departments of the Army, the Navy and the Air Force, April 1971.

[3] Driscoll, Fletcher, G., Ground Water and Wells, Johnson Division, St. Paul, MN 1986.

[4] *Ground Water Manual*, Bureau of Reclamation, U.S. Department of the Interior, 1st Edition, revised reprint, 1981.

[5] Leonards, G.A., Editor, *Foundation Engineering*, McGraw-Hill Book Co., Inc., New York, NY 1962.

[6] Powers, J. Patrick, *Construction Dewatering*, John Wiley and Sons, New York, NY 1981.

[7] Practical Construction Dewatering, Joint AEG-ASCE Symposium, Baltimore, May 16, 1975.

Chapter 18
GEOLOGIC ASPECTS OF BLAST DESIGN

Introduction

In blasting, as with most other construction problems, the geologist is the last to be called and is usually not called until serious difficulties have occurred. At this point, the geologist is required to provide an instant analysis and solution. This chapter provides a short introduction to blasting techniques so the geologist can relate to the problem at hand. This chapter was taken primarily from Richard Dick's *Explosives and Blasting Procedures Manual* [1] and, along with the *Blaster's Handbook* [2] should give the geologist a firm foundation in blasting techniques.

Blast design is not a precise science. Because of widely varying properties of rock, the geologic structure, and explosives, it is impossible to set down a series of equations which will enable the design of an ideal blast without field testing. Tradeoffs frequently must be made in designing the best blast for a given geologic situation and this chapter provides the fundamental concepts of blast design. These concepts are useful as a first approximation for blast design and also in troubleshooting the cause of a bad blast. Field testing is required to refine the individual blast dimensions.

Throughout the blast design process, two overriding principles must be kept in mind: (1) Explosives function best when there is a free face approximately parallel to the explosive column at the time of detonation and (2) there must be adequate space into which the broken rock can move and expand. Excessive confinement of explosives is the leading cause of poor blasting results such as backbreak, ground vibrations, airblast, unbroken toe, flyrock, and poor fragmentation.

Many of the principles discussed were presented first by Ash [3] and later reported by Pugleise [4] and Dick [5] during a study of quarrying practices in this country.

Properties and Geology of the Rock Mass

The character of the rock mass is the single most critical variable affecting the design and results of a blast. However, the nature of rock is very qualitative and cannot be sufficiently quantified numerically when applied to blast design. Rock character often varies greatly from one end of a construction job to another. Decisions on explosive selection, blast design, and delay pattern must take firsthand knowledge of the rock mass into account. For this reason, the onsite blaster and geologist usually have a significant advantage over an outside consultant in designing a blast. Although the number of variations in the character of rock is practically infinite, a general discussion of the subject will be helpful.

Characterizing the Rock Mass

The keys to characterizing the rock mass are a good geologist and a good blasting driller. The geologist must concentrate on detailed mapping of the rock surface for blast design. Jointing probably has the most significant effect on blasting design. The geologist should document the direction, severity, and spacing between the joint sets. In most sedimentary rocks there are at least three joint sets, one dominant and two less pronounced. The strike and dip of bedding planes foliation and/or schestosity are also important to blast design and should be well documented by the geologist. The presence of major zones of weakness such as faults, open joints, open beds, solution cavities, or zones of less competent rock or unconsolidated material are also important to blast design and must be determined. Samples of freshly broken rock can be used to determine the hardness and density of the rock.

An observant blasting driller can be of great help in assessing rock variations that are not apparent from the surface. Slow penetration, excessive drill noise, and vibration indicate a hard rock that will be difficult to break. Fast penetration and a quiet drill indicate a softer, more easily broken zone of rock. Total lack of resistance to penetration, accompanied by a lack of cuttings or return water or air, means that the drill has hit a void zone. Lack of cuttings or return water may also indicate the presence of an open bedding plane or other crack. A detailed drill log indicating the depth at which these various conditions exist can be very helpful to the person designing and loading the blast. The driller should also document changes in the color or nature of the drill cuttings, which will tell the blaster the location of various beds in the formation.

Rock Density and Hardness

Some amount of displacement is required to prepare a muckpile for efficient excavation. The density of the rock is a major factor in determining how much explosive is needed to displace a given volume of rock (powder factor). The burden-to-charge diameter ratio, which will be discussed in the next section, "Surface Blasting," varies with rock density, causing the change in powder factor. The average burden-to-charge diameter ratio of 25 to 30 is for average density rocks of typical rocks listed in table 18-1. Denser rocks such as basalt and dunite require smaller ratios (higher powder factors). Lighter materials such as some sandstone or bituminous coal can be blasted with higher ratios (lower powder factors).

The hardness or brittleness of rock can have a strong effect on blasting results. If soft rock is slightly underblasted, it probably still will be diggable. If soft rock is slightly overblasted, excessive violence will not usually occur. On the other hand, slight underblasting of hard rock will often re-

Table 18-1. – Typical rocks, densities, and unit weights.

Rock type	Density range (g/cm^3)	Range of unit weights	
		U.S. Customary lb/ft^3	S.I. metric kg/m^3
Limestone	2.5 to 2.8	156 to 174.7	2500 to 2800
Schist	2.6 to 2.8	162.2 to 174.7	2600 to 2800
Rhyolite	2.2 to 2.7	137.2 to 168.5	2200 to 2700
Basalt	2.7 to 2.9	168.5 to 181	2700 to 2900
Dunite	3.2 to 3.4	199.7 to 212.2	3200 to 3400
Sandstone	2.0 to 2.6	124.8 to 162.2	2000 to 2600
Bituminous coal	1.2 to 1.5	74.9 to 93.6	1200 to 1500

sult in a tight muckpile that is difficult to dig. Overblasting of hard rock is likely to cause excessive flyrock and airblast. Blast designs for hard rock, then, require closer control and tighter tolerances than those for soft rock.

Voids and Zones of Weakness

Unforeseen voids and zones of weakness such as solution cavities, "mud" seams, and shears are serious problems in blasting. Explosive energy always seeks the path of least resistance. Where the rock burden is composed of alternate zones of hard material, weak zones, or voids, the explosive energy will be vented through the weak zones and voids resulting in poor fragmentation. Depending on the orientation of zones of weakness with respect to free faces, excessive violence in the form of airblast and flyrock may occur. A particular problem occurs when the blasthole intersects a void. In this situation, unless particular care is taken in loading the charge, the void will be loaded with a heavy concentration of explosive, resulting in excessive airblast and flyrock.

If these voids and zones of weakness can be identified, steps can be taken during borehole loading to improve fragmentation and avoid violence. The best tool for this is a good drill log. The depths of voids and zones of weakness encountered by the drill should be documented. The geologist can help by plotting the trends of "mud" seams and shears. When charging the blasthole, inert stemming materials, rather than explosives, should be loaded through these weak zones. Voids should be filled with stemming. Where this is impractical because of the size of the void, it may be necessary to block the hole just above the void before continuing the explosive column.

Where the condition of the borehole is in doubt, the top of the powder column should be checked frequently as loading proceeds. If the column fails to rise as expected, there is probably a void. At this point a deck of inert stemming material should be loaded before powder loading continues. If the column rises more rapidly than expected, frequent checking will assure that adequate space is left for stemming.

Alternate zones of hard and soft rock usually result in unacceptable blocky fragmentation. A higher powder factor seldom will correct this problem; it will merely cause the blocks to be displaced farther. Usually the best way to alleviate this situation is to use smaller blastholes with smaller blast pattern dimensions to get a better powder distribution. The explosive charges should be concentrated in the hard rock.

Jointing

Jointing can have a pronounced effect on both fragmentation and the stability of the perimeter of the excavation. Close jointing usually results in good fragmentation. However, widely spaced jointing, especially where the jointing is pronounced, often results in a very blocky muckpile because the joint planes tend to isolate large blocks in place. Where the fragmentation is unacceptable, the best solution is to use smaller blastholes with smaller blast pattern dimensions. This extra drilling and blasting expense will be more than justified by the savings in loading, hauling, and crushing costs and the savings in secondary blasting.

Where possible, the perimeter holes of a blast should be aligned with the principal joint sets. This produces a more stable excavation, whereas rows of holes perpendicular to a primary joint set produces a more ragged, unstable perimeter (fig. 18-1). Generally the jointing will determine how the corners at the back of the blast will break out. To minimize backbreak and flyrock, tight corners, shown in figure 18-2, should be avoided.

The open corner at the left of the figure is preferable. Given the predominant jointing in figure 18-2, more stable conditions will result if the first blast is opened at the far right and designed so that the hole in the rear inside corner contains the highest numbered delay.

Bedding/Foliation

Bedding also has an effect on both the fragmentation and the stability of the excavation perimeter. Open bedding planes, open joints or beds of weaker materials should be

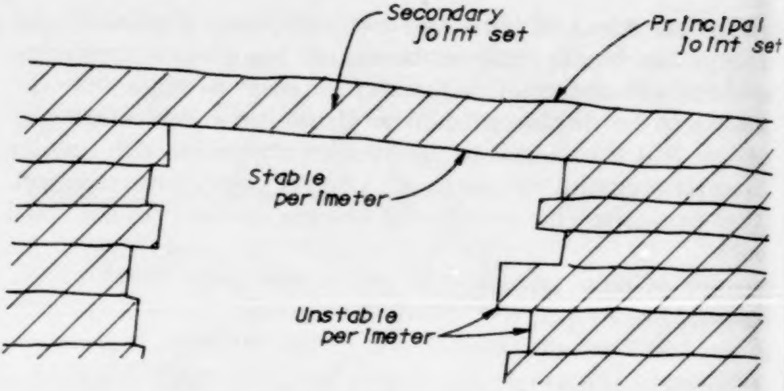


Figure 18-1. – Effect of jointing on the stability of an excavation (plan view).

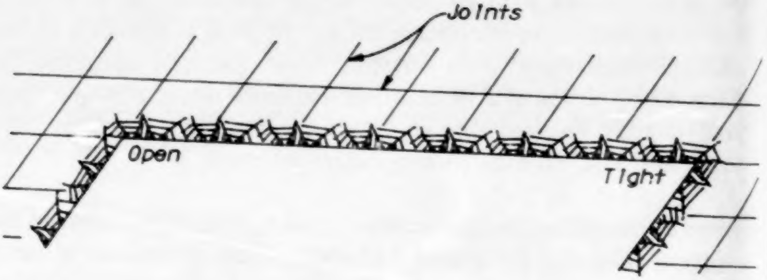


Figure 18-2. – Tight and open corners caused by jointing (plan view).

treated as zones of weakness. Stemming, rather than explosive, should be loaded into the borehole at the location of these zones as shown in figure 18-3. In a bed of hard material (greater than 3 feet [1 meter] thick), it is often beneficial to load an explosive of higher density than is used in the remainder of the borehole. To break an isolated bed or zone of hard rock (3 feet [1 meter] thick or greater) near the collar of the blasthole, a deck charge is recommended, as shown in figure 18-4, with the deck being fired on the same delay as the main charge or one delay later. Occasionally, satellite holes are used to help break a hard zone in the upper part of the burden. Satellite holes (fig. 18-4) are short holes, usually smaller in diameter than the main blastholes, which are drilled between the main blastholes.

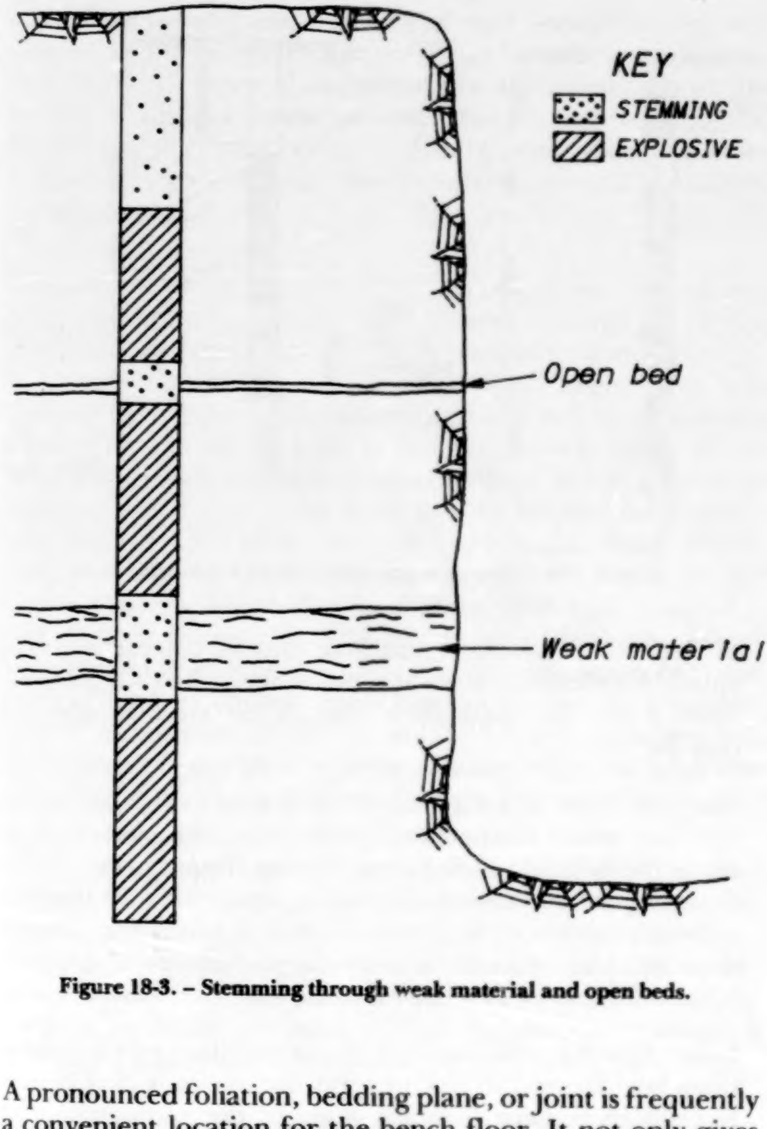


Figure 18-3. – Stemming through weak material and open beds.

A pronounced foliation, bedding plane, or joint is frequently a convenient location for the bench floor. It not only gives a smoother floor but also may reduce subdrilling requirements.

Dipping beds frequently cause stability problems and difficulty in breaking the toe of the excavation. When bedding or foliation dip into the excavation wall, the stability of the slope is enhanced. However, when they dip outward from the wall they form slip planes that increase the likelihood

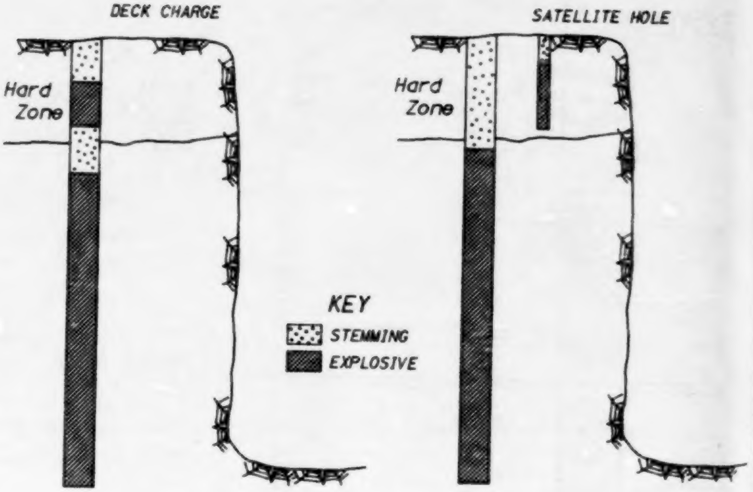


Figure 18-4. – Two methods of breaking a hard collar zone.

of slope deterioration. Blasthole cutoffs caused by differential bed movement are also more likely. Beds dipping outward from the final slope should be avoided wherever possible.

Although beds dipping into the face improve slope stability, they can create toe problems as the toe rock tends to break along the bedding or foliation planes. Dipping beds such as these require a tradeoff, depending upon which is the more serious problem in the job at hand, a somewhat unstable slope or an uneven toe. In some cases advancing the opening perpendicular to the dipping beds may be a compromise.

Many blasting jobs encounter site-specific geologic conditions not covered in this general discussion. Good blasting techniques require constant study of the geology to make every effort to use the geology to advantage, or at least minimize its unfavorable effects in blast designs.

Surface Blasting

Blasthole Diameter

The size of blasthole is the first consideration of any blast design. The blasthole diameter, along with the type of explosive being used and the type of rock being blasted, will determine the burden (distance from blast hole to nearest free face). All other blast dimensions are a function of the burden. This discussion assumes that the blaster has the freedom to select the borehole size. In many operations one is limited to a specific size borehole based on available drilling equipment.

Practical blasthole diameters for surface, construction excavations range from 3 (75 mm) to approximately 9 inches (230 mm). As a general rule, large blasthole diameters yield low drilling and blasting costs because large holes are cheaper to drill per unit volume, and less sensitive, cheaper blasting agents can be used in larger diameter holes. However, larger diameter blastholes also result in large burdens and spacings; hence, they tend to give coarser fragmentation. Figure 18-5 illustrates this comparison using 2- (50 mm) and 20-inch (508 mm) diameter blastholes as an example. Pattern A contains four 20-in (508 mm) blastholes and pattern B contains 400 2-in (5mm) blastholes. In all bench blasting operations some compromise between these two extremes is chosen. Each pattern represents the same area of excavation, 15,000 sq ft (1393.5 m^2), each involves approximately the same volume of blastholes, and each can be loaded with about the same weight of explosive.

As a general rule, large diameter blast holes (6 to 12 inches) [152 to 305 mm] have limited applications on most construction projects due to the requirements for fine fragmentation and the use of relatively shallow cuts. However, borehole size depends primarily on local conditions. When used, large holes are most efficient in deep cuts where a free face has already been developed.

In most Reclamation construction projects, small diameter drilling with high-speed equipment provides relatively low unit costs and permits fairly close spacing of holes. This close spacing allows for better distribution of explosives throughout the rock mass, which in turn produces better breakage. An additional advantage of small-diameter blast holes is the reduction in the amount of each explosive used in each hole which, in turn, reduces ground vibrations. Usually construction blasting hole diameters vary from 3.5 to 4.5 inches (90

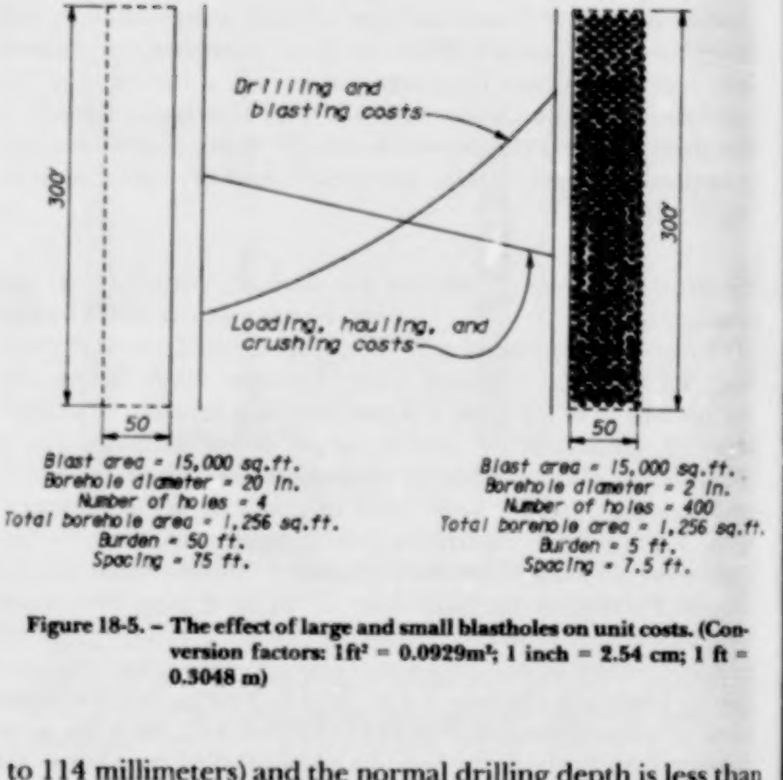

Drilling and blasting costs
Loading, hauling, and crushing costs
300'
50
300'
50
Blast area = 15,000 sq.ft.
Borehole diameter = 20 in.
Number of holes = 4
Total borehole area = 1,256 sq.ft.
Burden = 50 ft.
Spacing = 75 ft.
Blast area = 15,000 sq.ft.
Borehole diameter = 2 in.
Number of holes = 400
Total borehole area = 1,256 sq.ft.
Burden = 5 ft.
Spacing = 7.5 ft.

Figure 18-5. – The effect of large and small blastholes on unit costs. (Conversion factors: 1ft^2 = 0.0929m^2; 1 inch = 2.54 cm; 1 ft = 0.3048 m)

to 114 millimeters) and the normal drilling depth is less than 40 feet (12 meters). However, Reclamation generally limits blast hole diameters for structural excavation drilling to 3.5 inches (90 millimeters). Blasting patterns usually ranges from 6 × 8 feet (1.8 × 2.4 meters) to 8 × 15 feet (2.4 × 4.6 meters) and are usually rectangular with the burden being less than the spacing.

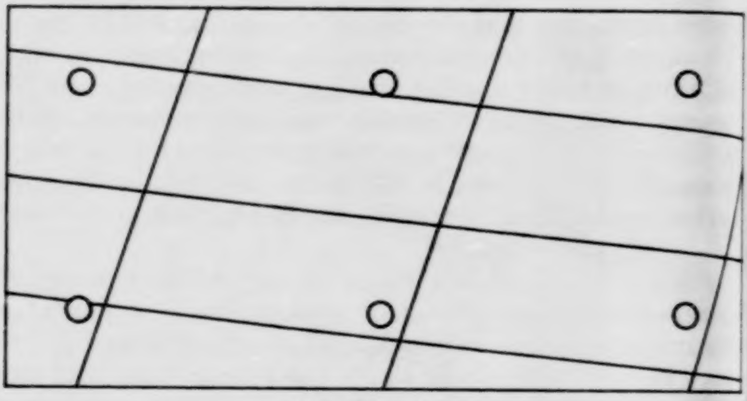
In a given rock type, a four-hole pattern will give relatively low drilling and blasting costs. Drilling costs for the large blastholes will be low, a low-cost blasting agent will be used, and the cost of detonators will be minimal. However, in a difficult blasting situation, the broken material will be blocky and nonuniform in size, resulting in higher loading, hauling, and crushing costs as well as requiring more secondary breakage. Insufficient breakage at the toe may also result.

On the other hand, the 400-hole pattern will yield high drilling and blasting costs. Small holes cost more to drill per unit volume, powder for small-diameter blastholes is usually more expensive, and the cost of detonators will be higher. However, the fragmentation will be finer and more uniform, resulting in lower loading, hauling, and crushing costs. Secondary blasting and toe problems will be minimized. Size of equipment, subsequent processing required for the blasted material, and economics will dictate the type of fragmentation needed, and hence the size of blasthole to be used.

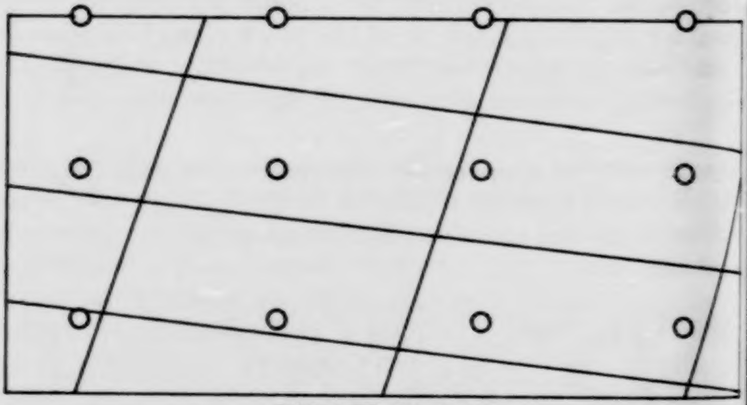
Geologic structure is a major factor in determining the blasthole diameter. Planes of weakness such as joints, and shears, or zones of soft rock tend to isolate large blocks of rock in the burden. The larger the blast pattern, the more likely these blocks are to be thrown unbroken in the muckpile. Note that in the top pattern in figure 18-6 some of the blocks are not penetrated by a blasthole, whereas in the smaller bottom pattern all of the block contain at least one blasthole. Owing to the better explosives, distribution, the bottom pattern will give better fragmentation.

As more blasting operations are carried out near populated areas, environmental problems such as airblast and flyrock often occur due to an insufficient collar distance (stemming column) above the explosive charge. As the blasthole diameter increases, the collar distance required to prevent violence increases. The ratio of collar distance to blasthole diameter required to prevent violence varies from 14:1 to 28:1, depending on the relative densities and velocities of the explosive and rock, the physical condition of the rock, the type of stemming used, and the point of initiation. A larger collar distance is required where the sonic velocity of the rock exceeds the detonation velocity of the explosive or where the rock is heavily fractured or low in density. A top-initiated charge requires a larger collar distance than a bottom-initiated charge. As the collar distance increases, the powder distribution becomes poorer resulting in poorer fragmentation of the rock in the upper part of the bench.

Ground vibrations are controlled by reducing the weight of explosive fired per delay interval. This is done more easily with small blastholes than with large blastholes. In many situations where an operator uses large-diameter blastholes near populated areas, several delays along with decking must be used within each hole to control vibrations.



LARGER HOLES



SMALLER HOLES

Figure 18-6. – The effects of jointing on selection of blasthole size.

Ideally, large holes with large blast patterns are suited to an operation with the following characteristics: a large volume of material to be moved; large loading, hauling, and crushing equipment; no requirement for fine, uniform fragmentation; an easily broken toe; few ground vibration or airblast problems (few nearby buildings); and a relatively homogeneous, easily fragmented rock without excessive, widely spaced planes of weakness or voids. Many blasting jobs, however, present constraints that require smaller blastholes.

In the final analysis, the selection of blasthole size is based on economics. It is important to consider the economics of the overall excavation system. Savings realized through indiscrimination cost cutting in the drilling and blasting program may well be lost through increased loading, hauling, or crushing costs.

Types of Blast Patterns

Three drill patterns commonly used are: square, rectangular, and staggered. The square drill pattern (fig. 18-7) has equal burdens and spacing, while the rectangular pattern has a larger spacing than burden. In both the square and rectangular patterns, the holes of each row are lined up directly behind the holes in the preceding row. In the staggered pattern (fig. 18-7), the holes in each are positioned in the middle of the spacings of the holes in the preceding row. In the staggered pattern, the spacings should be larger than the burden.

The staggered drilling pattern is used for row-on-row firing; that is, where the holes of one row are fired before the holes in the row immediately behind them as shown in figure 18-8. The square or rectangular drilling patterns are used for

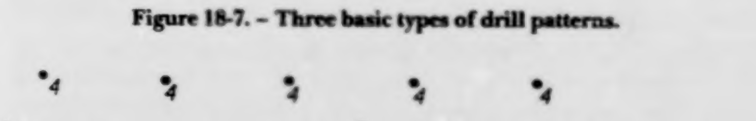


Figure 18-7. – Three basic types of drill patterns.

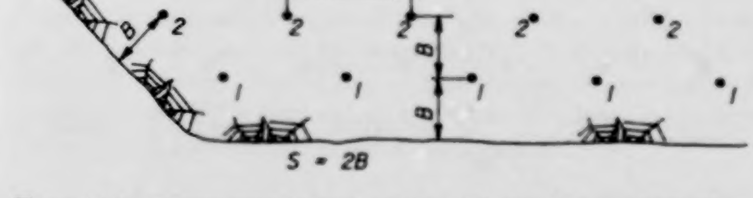


Figure 18-8. – Corner cut staggered pattern with simultaneous initiation within rows (Blasthole spacings, S, is twice the burden, B).

firing V-cut (fig. 18-9) or echelon rounds. Either side of the blast round in V-cut or echelon blast round the burdens and subsequent rock displacement are at an angle to the original free face. Looking at figure 18-9, with the burdens developed at a 45° angle with the original free face, the original square drilling pattern has been transformed to a staggered blasting pattern with a spacing twice the burden. The three simple patterns discussed here account for nearly all of the surface blasts fired.

Burden

Figure 18-10 is an isometric view showing the relationship of the various dimensions of a bench blast. The burden is defined as the distance from a blasthole to the nearest free face at the instant of detonation. In multiple row blasts, the burden for a blasthole is not necessarily measured in the direction of the original free face. One must take into account the free faces developed by blastholes fired on lower delay periods. As an example, in figure 18-8, where one entire row is blasted before the next row begins, the burden is measured in a perpendicular direction between rows.

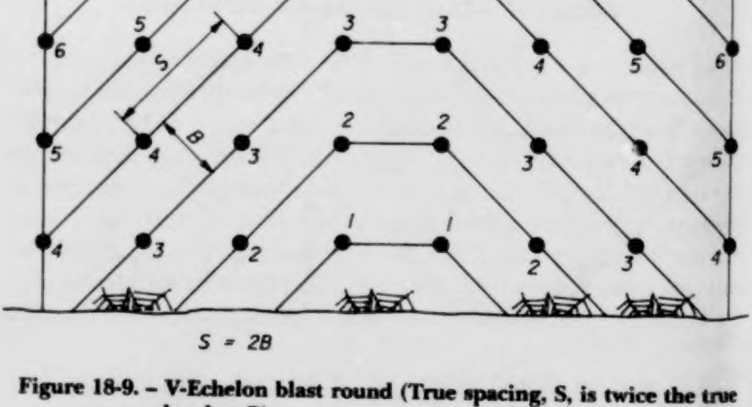


Figure 18-9. – V-Echelon blast round (True spacing, S, is twice the true burden, B).

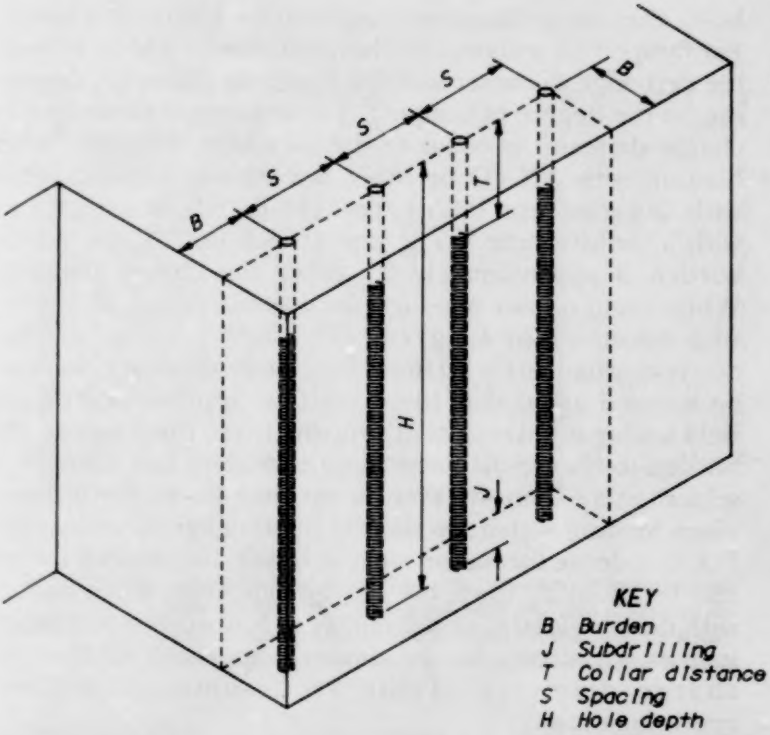


Figure 18-10. – Isometric view of a bench blast.

However, in figure 18-9 the blast progresses in a V-shape. In this situation, the true burden on most of the holes is measured at an angle of 45° from the original free face.

It is very important that the proper burden be calculated, taking into account the blasthole diameter, the relative density of the rock and the explosive, and to some degree, the depth of the blasthole. An insufficient burden will cause excessive airblast and flyrock. Too large a burden will produce inadequate fragmentation, toe problems, and excessive ground vibrations. Where necessary to drill a round before the previous round has been excavated, it is important to stake out the first row of the second round before the first round is fired. This will assure a proper burden on the first row of blastholes in the second blast round.

The burden dimension is a function of the charge diameter. For bulk-loaded charges (the charge is poured down the hole), the charge diameter is equal to the blasthole diameter. For tamped cartridges, the charge diameter will be between the cartridge diameter and the blasthole diameter, depending on the degree of tamping. For untamped cartridges the charge diameter is equal to the cartridge diameter. When blasting with AN-FO or other low density blasting agents with densities near 0.85 g/cm^3 (53 lb/ft^3), in typical rock with a density near 2.7 g/cm^3 (168.5 lb/ft^3), the normal burden is approximately 25 times the charge diameter. When using denser products such as slurries or dynamites, with densities near 1.2 g/cm^3 (74.9 lb/ft^3), the normal burden is approximately 30 times the charge diameter. It should be stressed again that these are first approximations, and field testing often results in adjustments to these values. The burden-to-charge-diameter ratio is seldom less than 20 or seldom more than 40, even in extreme cases. For instance, when blasting with a low density blasting agent, such as AN-FO, in a dense formation such as basalt, the desired burden may be about 20 times the charge diameter. When blasting with denser slurries or dynamites in low density formations such as sandstones, the burden may approach 40 times the charge diameter. Table 18-2 summarizes these approximations.

High-speed photographs of blasts have shown that flexing of the burden plays an important role in rock fragmentation. A relatively deep, narrow burden flexes, and thus breaks more easily than a shallow, wider burden. Figure 18-11

Table 18-2. – Approximate burden charge diameter ratios for bench blasting.

	Ratio
AN-FO (density — 0.85 g/cm^3)	
Light rock (density — 2.2 g/cm^3, 137.3 lb/ft^3)	28
Average rock (density — 2.7 g/cm^3)	25
Dense rock (density — 3.2 g/cm^3)	23
Slurry, dynamite (density — 3.2 g/cm^3; 199.7 lb/ft^3)	
Light rock (density — 2.2 g/cm^3)	33
Average rock (density — 2.7 g/cm^3)	30
Dense rock (density — 3.2 g/cm^3)	27

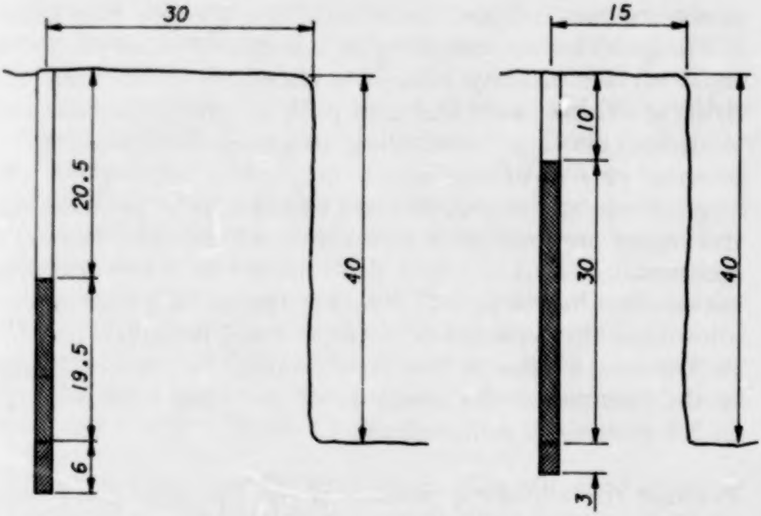


Figure 18-11. – Comparison of a 12 1/4–inch (305 mm) diameter blasthole (stiff burden) on the left with a 6–inch (152 mm) diameter blasthole (flexible burden) on the right in a 40–foot (12.2 meter) bench. (Figure dimensions given in feet).

shows the difference between using a 6-in (152 millimeter) blasthole and a 12.25-in (312 millimeter) blasthole in a 40-ft (12.2 meters) bench, with a burden-to-charge-diameter ratio of 30 and appropriate subdrilling and stemming dimensions. Note the inherent stiffness of the burden with 12.25-in (312 millimeter) blasthole as compared with the 6-in (152 millimeter) blasthole. Based on this consideration, lower burden-to-charge-diameter ratios should be used as a first approximation when the blasthole diameter is large in comparison to the bench height. However, care must be taken that the burden ratio is not so small as to create violence. Once the ratio has been determined, it becomes the basis for calculating subdrilling, collar distance (stemming), and spacing.

Subdrilling

Subdrilling is the distance drilled below the floor level to assure that the full face of rock is removed. Where there is a pronounced parting at floor level, to which the explosive charge can conveniently break, subdrilling may not be required. In coal strip mining, it is common practice to drill down to the coal and then backfill a foot or two before loading explosives, resulting in a negative subdrill; but, in most surface blasting jobs, it is necessary to do some subdrilling to make sure the shot pulls to grade. In most construction blasting, subdrilling is generally limited to 10 percent or less of the bench height. In blasting for civil engineering structures, where a final grade is specified, subdrilling of the final lift is severely restricted. The Bureau of Reclamation usually limits the final lift in structural excavations to 5 or 10 feet (1.5 to 3 meters). Subdrilling is not allowed in the 5 foot (1.5 meter) lift and is limited to 2 feet (0.6 meters) for the 10 foot (3 meter) lift. To prevent damage to the foundation the diameter of the blast hole is limited to 3.5 inches (90 millimeters).

Priming the explosive column at the toe level gives maximum confinement and normally gives the best breakage. Other factors being equal, toe priming usually requires less subdrilling than collar priming. Again, toe priming should be severely restricted in structural foundations.

Excessive subdrilling is a waste of drilling and blasting expense and also may cause excessive ground vibrations due to the high degree of confinement of the explosive in the bottom of the blasthole, particularly when the primer is placed in the bottom of the hole. In multiple-bench operations, excessive subdrilling may cause undue fracturing in the upper portion of the bench below, creating difficulties in collaring holes in the lower bench. Insufficient subdrilling causes high bottom resulting in increased wear and tear on equipment and expensive secondary blasting.

Collar Distance (Stemming)

Collar distance is the distance from the top of the explosive charge to the collar of the blasthole. This zone usually is filled with an inert material called **stemming** to give some confinement to the explosive gases and to reduce airblast. Research has shown that well graded crushed gravel works best as stemming, but it is common practice to use drill cuttings because of availability and economics. Collar distances that are too short result in excessive violence in the form of airblast and flyrock and may cause backbreak (breaking beyond the back wall). Collar distances that are too long create large blocks in the upper part of the bench. The selection of a collar distance is often a tradeoff between fragmentation and the amount of airblast and flyrock that can be tolerated. This is true especially where the upper part of the bench contains rock that is difficult to break or is of a different type. In this situation the difference between a violent blast and one that fails to fragment the upper zone properly may be a matter of only a few feet of stemming. Collar or direct priming (placing the primer at or near the collar of the blasthole with the blasting cap pointing toward the bottom of the hole) of blastholes normally causes more violence than center or toe priming, and requires the use of a longer collar distance.

Field experience has shown that a collar distance equal to 70 percent of the burden is a good first approximation except where collar priming is used. Careful observation of airblast, flyrock, and fragmentation will enable the blaster to further refine this dimension. Where adequate fragmentation in the collar zone cannot be attained while still controlling airblast and flyrock, deck charges or satellite (mid-spaced) holes may be required (fig. 18-4).

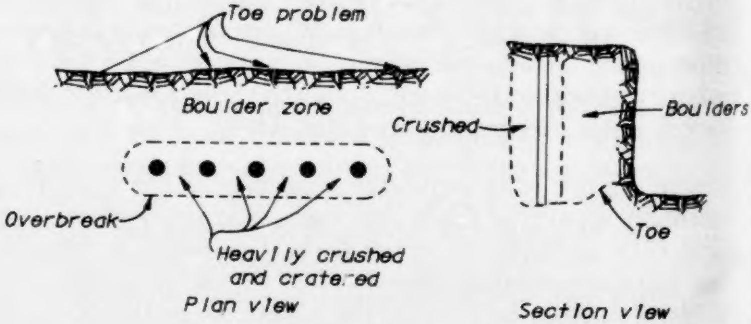
A deck charge is an explosive charge near the top of the blasthole, separated from the main charge by inert stemming. If large blocky materials are being created in the collar zone but the operator fears that less stemming would cause excessive airblast or flyrock, the main charge should be reduced slightly and a deck charge added. The deck charge is usually shot on the same delay as the main charge or one delay later. Care must be exercised not to place the deck charge too near the top of the blasthole, or excessive flyrock may result. As an alternative, short satellite holes between the main blastholes can be used. The diameter of the satellite holes are usually smaller than the main blastholes and are loaded with a light charge of explosives.

From the standpoint of public relations, collar distance is a very important blast design variable. One violent blast can permanently alienate neighbors. In a delicate situation, it may be best to start with a collar distance equal to the burden and gradually reduce this if conditions permit. Collar distances greater than the burden are seldom necessary.

Spacing

Spacing is defined as the distance between adjacent blastholes, measured perpendicular to the burden. Where the rows are blasted one after the other as in figure 18-8, the spacing is measured between holes in a row. However, where the blast progresses at an angle to the original free face, as in figure 18-9, the spacing is measured at the angle from the original free face.

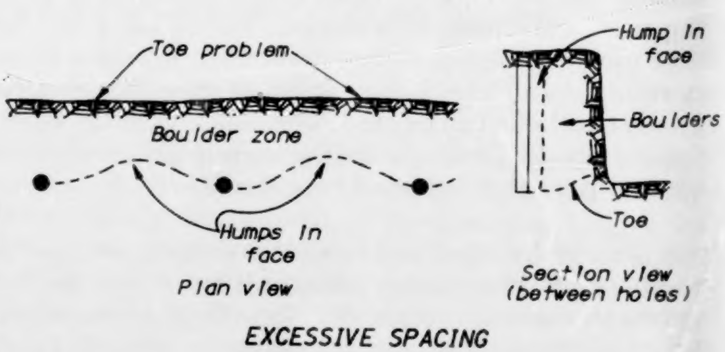
Spacing is calculated as a function of the burden and also depends on the timing between holes. Spacing that is too close causes crushing and cratering between holes, large blocks in the burden, and toe problems. Spacing that is too wide causes inadequate fracturing between holes, toe problems, and is accompanied by humps on the face (fig. 18-12).



Plan view

Section view

INSUFFICIENT SPACING



Plan view

Section view (between holes)

EXCESSIVE SPACING

Figure 18-12. – Effects of insufficient and excessive spacing.

When the holes in a row are initiated on the same delay period, a spacing equal to twice the burden usually will pull the round satisfactorily. The V-cut round in figure 18-9 illustrates simultaneous initiation within a row, with the rows being the angled lines of holes fired on the same delay. The true spacing is twice the true burden even though the holes originally were drilled on a square pattern.

Field experience has shown that the use of ms (millisecond) delays between holes in a row results in better fragmentation and also reduces the ground vibrations produced by the blast. When millisecond delays are used between holes in a row, the spacing-to-burden ratio must be reduced to somewhere between 1.2 and 1.8, with 1.5 being a good first approximation. Various delay patterns may be used within the rows, including alternate delays (fig. 18–13) and progressive delays (fig. 18–14). Generally, large-diameter blastholes require lower spacing-to-burden ratios (usually 1.2 to 1.5 with millisecond delays) than small-diameter blastholes (usually 1.5 to 1.8). Because of the complexities of geology, the interaction of delays, differences in explosive and rock strengths, and other variables, the proper spacing-to-burden ratio must be determined through onsite experimentation, using the preceding values as first approximations.

Except when using controlled blasting techniques such as smooth blasting and cushion blasting, described later, the spacing should never be less than the burden.

Hole depth

In any blast design it is important that the burden and the blasthole (or bench height) be reasonably compatible. As a rule of thumb for bench blasting, the hole depth-to-burden ratio should be between 1.5 and 4.0. Hole depths less than 1.5 times the burden cause excessive airblast and flyrock and, because of the short-thick shape of the burden, give coarse and uneven fragmentation. Where operational conditions require a ratio of less than 1.5, a primer should be placed at the toe of the bench to assure maximum confinement. Keep in mind that placing the primer in the subdrill can cause increased ground vibrations and unacceptable irregular final grades for engineering structures. If the blaster

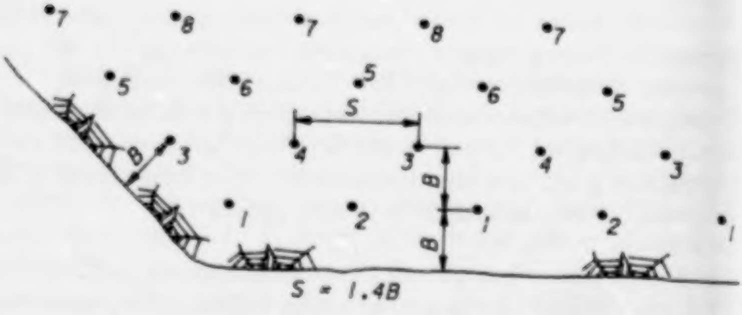


Figure 18-13. – Staggered blast pattern with alternate delays (Blasthole spacing, S, is 1.4 times the burden, B).

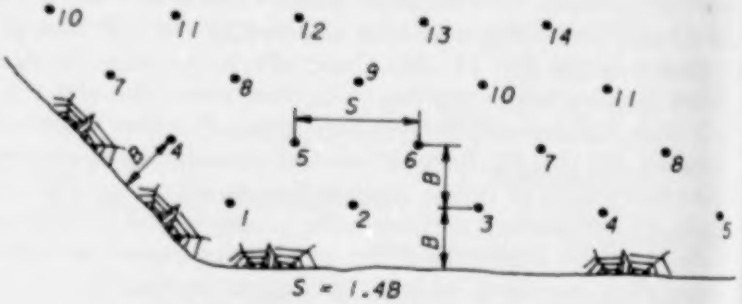


Figure 18-14. – Staggered blast pattern with progressive delays (Blasthole spacing, S, is 1.4 times the burden, B).

continually finds the use of a hole depth-to-burden ratio of less than 1.5 necessary or specified, consideration should be given to increasing the bench height or using smaller drill hole diameters.

Hole depths greater than four times the burden are also undesirable. The longer a hole is with respect to its diameter, the more error there will be in its location at toe level (hole wandering), which is the most critical portion of the blast. A poorly controlled blast will result. Extremely long, slender holes have even been known to intersect.

High benches with short burdens can also create safety hazards, such as a small drill having to put in the front row of holes near the edge of a high ledge or a small shovel having to dig at the toe of a precariously high face. The obvious solution to this problem is to use a lower bench height. There is no real advantage to a high bench height. Lower benches give more efficient blasting results, lower drilling costs less chances of cutoffs, and are safer from an equipment operation standpoint. If it is impractical to reduce the bench height, larger rock handling and drilling equipment should be used, which will effectively reduce the blasthole depth-to-burden ratio.

A major problem with long slender charges is the greater potential for cutoffs in the explosive column. Where it is necessary to use blast designs with large hole depth-to-burden ratios, multiple priming should be used as insurance against cutoffs.

Delays

Millisecond (ms) delays are used between charges in a blast round for three reasons:

1. To assure that a proper free face is developed to enable the explosive charge to efficiently fragment and displace the rock;

2. To enhance fragmentation between adjacent holes; and

3. To reduce the ground vibrations created by the blast.

Numerous delay patterns exist, several of which were covered in figures 18-8, 18-9, 18-13, and 18-14.

Andrews [6], conducted numerous field investigations to determine optimum delay intervals for bench blasting and reached the following conclusions:

1. The delay time between holes in a row should be between 1 and 5 ms per foot of burden. Delay times less than 1 ms per foot of burden cause premature shearing between holes, resulting in coarse fragmentation. If an excessive delay time is used between holes, rock movement from the first hole prevents the adjacent hole from creating additional fractures between the two holes. A

delay of 3 ms per foot of burden gives good results in many types of rock.

2. The delay time between rows should be two to three times the delay time between holes in a row. To obtain good fragmentation and control flyrock, a sufficient delay is needed so that the burden from previously fired holes has enough time to move forward to accommodate moving rock from subsequent rows. If the delay between rows is too short, movement in the back rows will be upward rather than outward (fig. 18-15).

3. Where airblast is a problem, the delay between holes in a row should be at least 2 ms per foot of spacing. This prevents airblast from one charge from adding to that of subsequent charges as the blast proceeds down the row.

4. For the purpose of controlling ground vibrations, most regulatory authorities consider two charges to be separate events if they are separated by a delay of 9 ms or more.

These conclusions apparently yield good blasting results. However, when using surface delay systems such as detonating cord connectors and sequential timers, the chances for cutoffs will be increased. To solve this problem, in-hole delays should be used in addition to the surface delays. For instance, when using surface detonating cord connectors, the use of 100 ms delays in each hole is suggested. This will

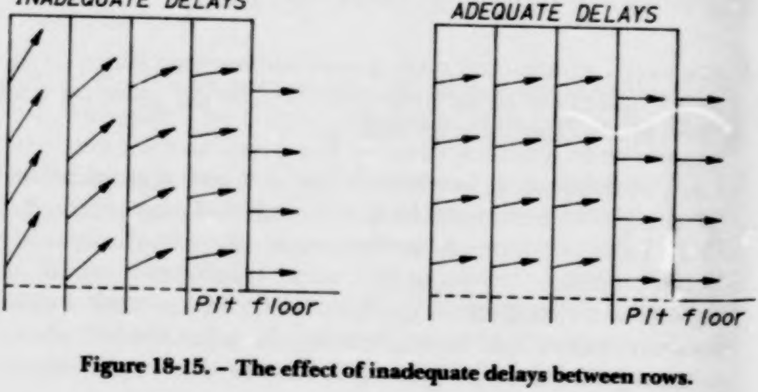


Figure 18-15. – The effect of inadequate delays between rows.

cause ignition of the in-hole delays well in advance of rock movement, thus minimizing cutoffs. With a sequential timer, the same effect can be accomplished by avoiding the use of electric caps with delays shorter than 75 to 100 ms.

From the standpoint of simplicity in blast design, it is best if all the explosive in a blasthole is fired as a single column charge. However, it is sometimes necessary, where firing large blastholes in populated areas, to use two or more delays within a blasthole to reduce ground vibrations. Blast rounds of this type can become quite complex, and should be designed under the guidance of a certified blaster.

All currently used delay detonators employ pyrotechnic delay elements. That is, they depend on a burning powder train for their delay. Although these delays are reasonably accurate, overlaps have been known to occur [7]. Therefore, when it is essential that one charge fires before an adjacent charge, such as in a tight corner of a blast, it is a good idea to skip a delay period.

Powder Factor

Powder factor, (lb. explosive/yd^3 rock) is not the best tool for designing blasts.

Blast designs should be based on the dimensions discussed earlier in this chapter. However, powder factor is a necessary calculation for cost accounting purposes. In blasting operations such as construction work where the excavated material has little or no inherent value, powder factor is usually expressed in terms of pounds of explosives per cubic yard of material broken. Powder factors for surface blasting can vary from 0.25 to 2.5 lb/yd^3 (0.1 to 1.1 kg/m^3), with 0.5 to 1.0 lb/yd^3 (0.2 to 0.45 kg/m^3) being most typical.

Powder factor for a single blasthole is calculated by the following:

$$P.F. = \frac{L(0.340d)\,(D^2)}{(B)\,(S)\,(H)\,(27)}$$

where $P.F$ = powder factor (pounds of explosive per cubic yard of rock),
L = length of the explosive charge (feet),
d = density of the explosive (grams per cubic centimeter),
D = charge diameter (inches),
B = burden dimension (feet),
S = spacing dimension (feet),
and H = bench height, (feet).

Many companies that provide explosives also publish tables that give loading densities in pounds per foot (0.3 meter) of blasthole for different combinations of d and D. A common nomograph found in most blasting handbooks ([2], pg. 41) can be used to calculate the density in pounds per foot (0.3 meter) of borehole. The powder factor is a function of the explosive type, rock density, and geologic structure. Table 18-3 includes typical powder factors for surface blasting.

Higher energy explosives, such as those containing large amounts of aluminum, can break more rock per pound than lower energy explosives. However, most of the commonly (lower energy) used explosive products have fairly similar energy values and thus have similar rock breaking capabilities. Soft, low density rock requires less explosive per cubic yard than hard, dense rock. Large-hole patterns require less explosive per cubic yard of rock because a larger portion of stemming is used. Poor powder distribution in larger diameter blastholes frequently result in coarser fragmentation. Massive rock with few existing planes of weakness requires a higher power factor than a rock unit with numerous, closely spaced joints or fractures. Finally, the more free faces a blast has to break to, the lower the powder factor requirement. For instance a corner cut, (fig. 18-8) with two

Table 18-3. – Typical powder factors for surface blasting.

Degree of difficulty in rock breakage	Powder factor	
	(lb/yd^3)	(kg/m^3)
Low	0.25-0.40	0.1-0.18
Medium	.40- .75	0.18-0.34
High	.75-1.25	0.34-0.57
Very high	1.25-2.50	0.57-1.14

vertical free faces, requires less powder than a box cut (fig. 18-9) or angled cuts (fig. 18-16) with only one vertical free face; which in turn, will require less powder than a shaft sinking type or parallel cut (fig. 18-16), in which there are no free faces. In a shaft sinking cut it is desirable, where possible, to open a second free face by creating a V-cut somewhere near the center of the round. V-cuts are discussed in the "Underground Blasting" section of this chapter.

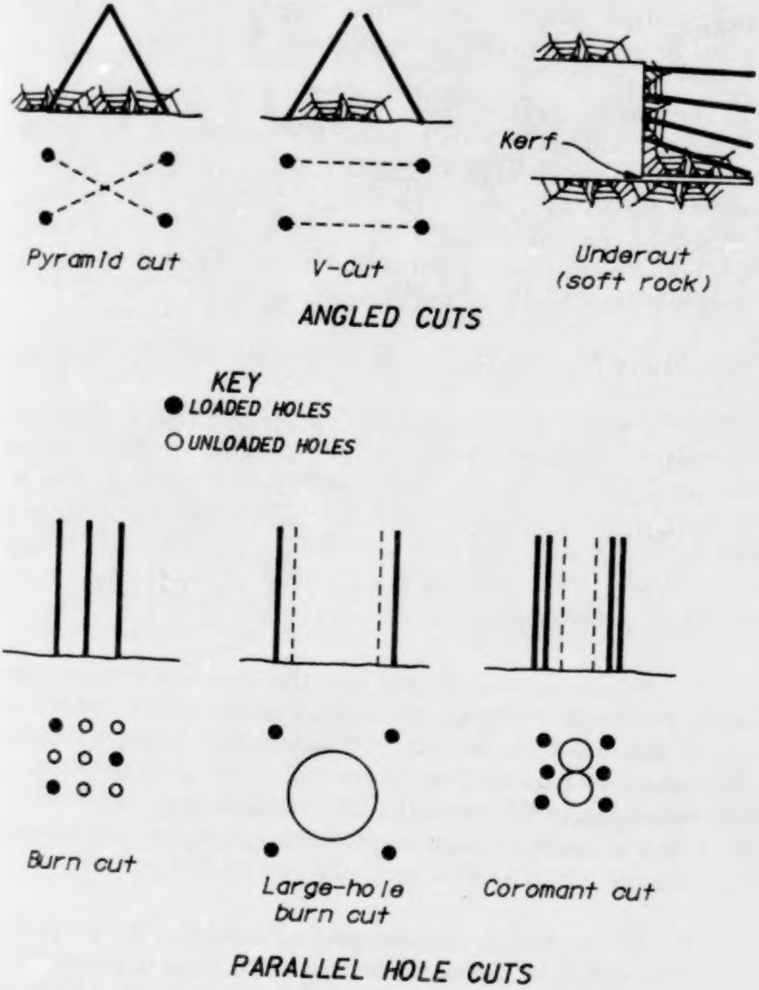


Figure 18-16. – Types of opening cuts.

When blasting materials have an inherent value per ton, such as aggregates or ores, the powder factors then are expressed as pounds of explosives per ton of rock or tons of rock per pound of explosive.

Secondary Blasting

Some primary blasts, no matter how well designed, will result in fragments too large to be handled efficiently by the loading equipment, and will cause plugging of crushers or preparation plants. Secondary fragmentation techniques must be used to break these oversize fragments.

In the case of fragments too large to be handled, the loader operator will set the rock aside for treatment. Identifying material large enough to cause crusher plugging is not always quite so apparent. The loader operator must be knowledgeable enough to watch for material that is small enough for convenient loading but which is too large for the crusher and will bottleneck in the processing cycle.

Secondary fragmentation can be accomplished in four ways:

1. A heavy ball (commonly referred to as a "headache ball") suspended from a crane may be dropped repeatedly on the oversize fragment until it breaks. This is a relatively inefficient method, and breaking a large or tough (nonbrittle) rock may take a considerable amount of time. This method is adequate where the number of oversize fragments is not excessive.

2. A hole may be drilled into the oversize fragment and a hydraulic wedging device inserted to split it. This is also a slow method but may be satisfactory where a limited amount of secondary fragmentation is necessary. An advantage to this method is that it does not create the flyrock associated with explosive techniques or, to some degree with the first method.

3. An explosive may be packed loosely into a crack or depression in the oversize fragment then covered with a dampen earthen material, and fired. This type of charge is called a mudcap, plaster, or adobe charge. This method

is inefficient due to the lack of explosive confinement, and relatively large amounts of explosives are required. Other results are excessive noise, flyrock, and often, inadequate fragmentation. This system is also hazardous because the primed charge, lying on the surface, is prone to accidental initiation by external impacts from falling rocks or equipment. External charges should be used to break boulders only where drilling is impractical, and when used, extreme caution must be exercised.

4. The most efficient method of secondary fragmentation is through the use of small (1- to 3-in) (25- to 75-mm) blastholes. The blasthole is normally collared at the most convenient location such as a crack or depression in the rock, and is directed toward the center of the mass. The hole is drilled two-thirds to three-fourths of the way through the rock. Because the powder charge is surrounded by free faces, less explosive is required to break a given amount of rock than in primary blasting. One-quarter pound per cubic yard (0.1 kg per cubic meter) usually will do the job. Careful location of the charge is more important than its precise size. When in doubt it is best to estimate on the low side and underload the hole. For larger fragments it is best to drill several holes and distribute the explosive charge rather than place the entire charge in a single hole. All secondary blastholes should be stemmed. Usually secondary blasts are more violent than primary blasts. Any type of initiation system may be used to initiate a secondary blast and for connecting large numbers of oversize fragments, where noise is not a problem, detonating cord often is used.

Although secondary blasting employs relatively small charges its potential safety hazards must not be underestimated. Usually flyrock is more severe and more difficult to predict than with primary blasting. Secondary blasting can truly be called an art; here experience is the important key to success.

Underground Blasting

For this manual, underground blast rounds are to be divided into two basic categories: (1) heading, drift, or tunnel rounds, in which the only free face is the surface from which the holes are drilled; and (2) bench or stope rounds in which there is one or more free faces in addition to the face on which the blastholes are drilled. In the second category blast-rounds are designed in the same manner as surface blast rounds. Only the blastrounds that are in the first category (those with only one initial free face) will be discussed.

Opening Cuts

The initial and most critical part of a heading round is the opening cut. The essential function of this cut is to provide additional free faces to which the rock can be broken. The du Pont *Blaster's Handbook* [2] discusses opening cuts. Although there are many specific types of opening cuts, and the terminology can be quite confusing, all opening cuts fall into one of two classifications; angled cuts, or parallel hole cuts (fig. 18-16).

An angled cut, which may be referred to as a V-cut, draw cut, slab cut, or pyramid cut, breaks out a wedge of rock to create an opening to which the remaining burden can be displaced. Angled cuts are very difficult to drill accurately. The bottoms of each pair of cut holes should be as close as possible, but must not cross. If they cross, the depth of round pulled will be less than designed. If the hole bottoms are more than a foot or so apart, the round may not pull to its proper depth. The angle between the cut holes should be 60° or more, to minimize bootlegging (unfired holes). One method to ensure a standard angled cut is to supply the drillers with a template with the proper spacing and angles for the angled holes. The selection of the specific type of angled cut is a function of the rock, the type of drilling equipment, and the philosophy of the blasting supervisor. A considerable amount of trial and error usually is involved in determining the best angled cut for a specific site. In small diameter tunnels with narrow headings it is often impossible to position the drill properly to drill an angled cut. In this case a parallel hole cut must be used.

Parallel hole cuts, which also may be called Michigan cuts, Cornish cuts, shatter cuts, burn cuts, or Coromant cuts, are basically a series of closely spaced holes, some loaded and some unloaded (fig. 18-17) which, when fired, pulverize and eject a cylinder of rock to create an opening to which the remaining burdens can be broken. Because they require higher powder factors and more drilling per volume of rock blasted, the use of parallel hole cuts usually is restricted to narrow headings, where there is not enough room to drill an angled cut.

Parallel hole cuts involve more drilling than angled cuts because the closely spaced holes break relatively small volumes of rock. However, they are relatively easy to drill because the holes are parallel. Like angled cuts, accurately drilled parallel hole cuts are essential if the blast round is to be effective. Some drill jumbos have automatic controls to assure that holes are drilled parallel. Units of this type are a good investment where parallel hole cuts will be drilled routinely. A template also may be used in drilling a parallel hole cut.

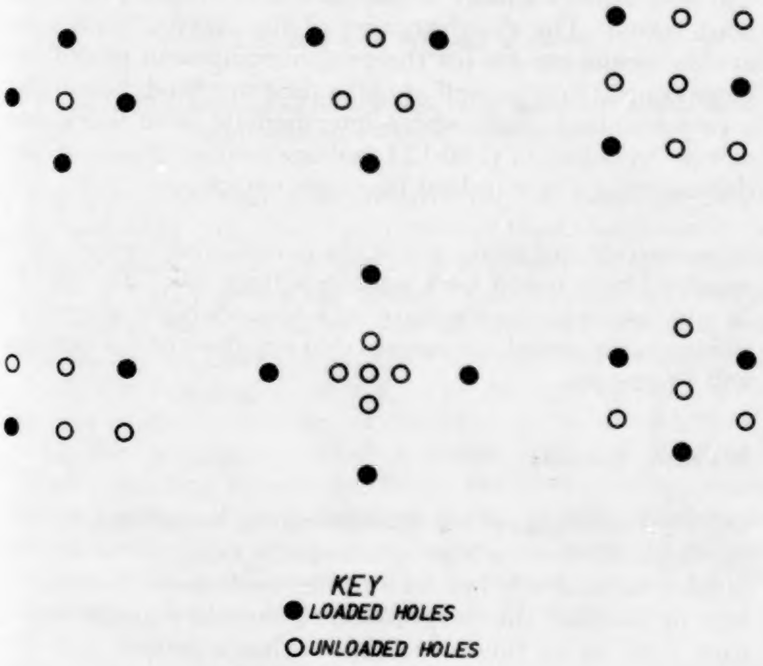


Figure 18-17. – Six designs for parallel hole cuts.

The selection of the type of parallel hole cuts also depends on the rock, the type of drilling equipment, and the philosophy of the blasting supervisor. As with angled cuts trial and error usually is involved in determining the best parallel hole cut for a specific site.

For all types of opening cuts it is important that the cut pulls to its planned depth, because the remainder of the round will not pull more deeply than the cut. In blasting with burn cuts, care must be exercised to prevent overloading of the burn holes, as overloading may cause the cut to "freeze" or not pull properly. The design of the cut depends upon the type of rock, and often must be designed and redefined by trial and error.

Some research has been done involving burn cuts with one or more large unloaded central holes [7]. The advantage of the large central hole is that it gives a dependable void (free face) to which succeeding holes can break. This situation is not always obtained with standard burn cuts. The large central hole assures a more dependable and deeper pull of the blast round. The disadvantages of the large central holes are the requirements for the proper equipment to drill the large central hole as well as extra time involved. Sometimes a compromise is used where intermediate-sized holes, usually 4- to 5-inches (100-127 millimeters) in diameter, are drilled using the standard blasthole equipment.

In some soft materials, particularly coal, the blasted cut is replaced by a sawed kerf, usually a floor level (fig. 18-18). In addition to giving the material a dependable void in which to break, the sawed cut assures that the floor of the opening will be smooth.

Blasting Rounds

Once the opening cut has established the necessary free face, the remainder of the blastholes must be designed so that the burden successively breaks into the void space. It is important to visualize the progression of the blast round so that each hole, at its time of initiation, has a proper free face parallel or nearly parallel to it. Figure 18-19 gives the typical nomenclature for blastholes in a heading round.

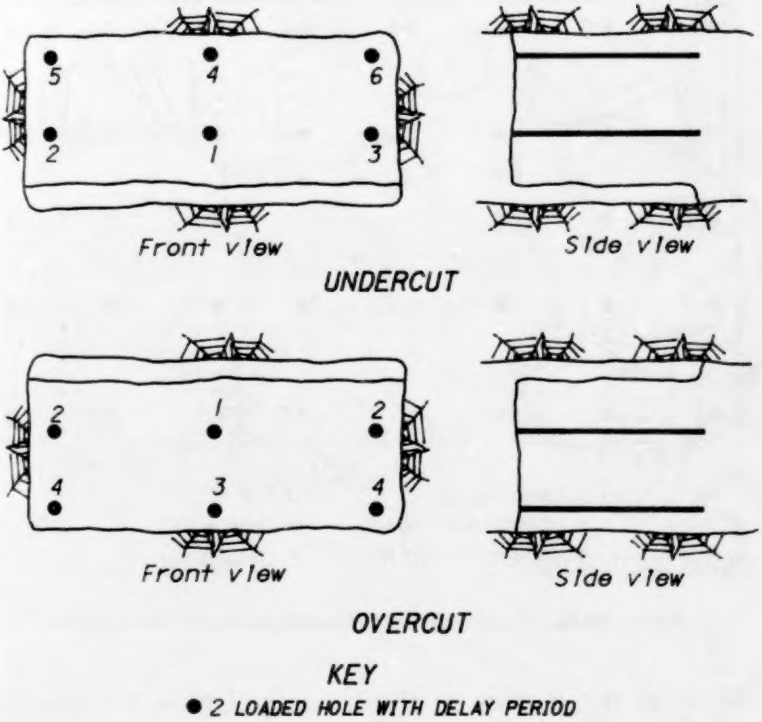


Figure 18-18. – Blast round for soft rock using sawed kerf (numbers on loaded holes show delay in milliseconds).

The holes fired immediately after the cut holes are called the **relievers**. The burden between these holes must be planned carefully. If the burden is too small the charges will not pull their share of the round. If the burden is too large the round may freeze because of insufficient space into which the rock can expand. After several relievers have been fired, the opening usually is large enough to permit the design of the remainder of the blast to be in accordance with the principles discussed under "Surface Blasting". Where heading rounds are large, the burden and spacing ratio usually is slightly less than those for surface blasts. In small headings, where space is limited, the burden and spacing ratio will be still smaller. This is another area where trial and error plays an important part in blast design.

The last holes to be fired in an underground round are the back holes at the top, the rib holes at the sides, and the

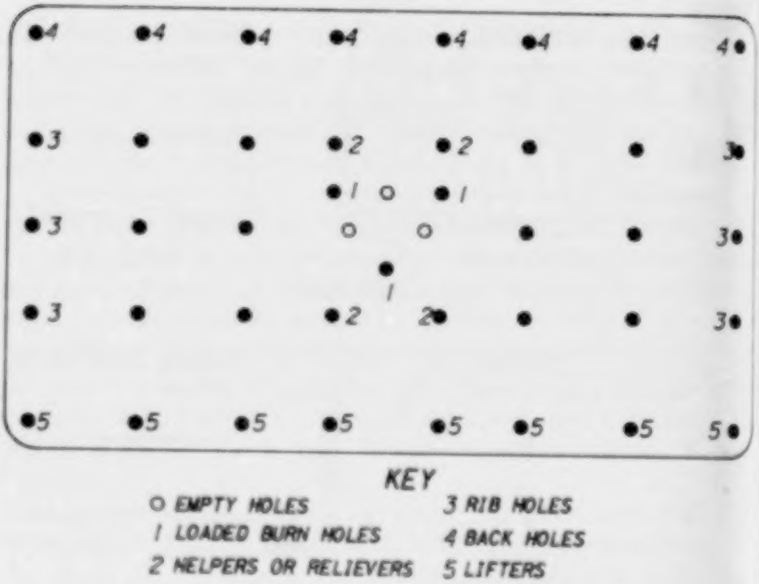
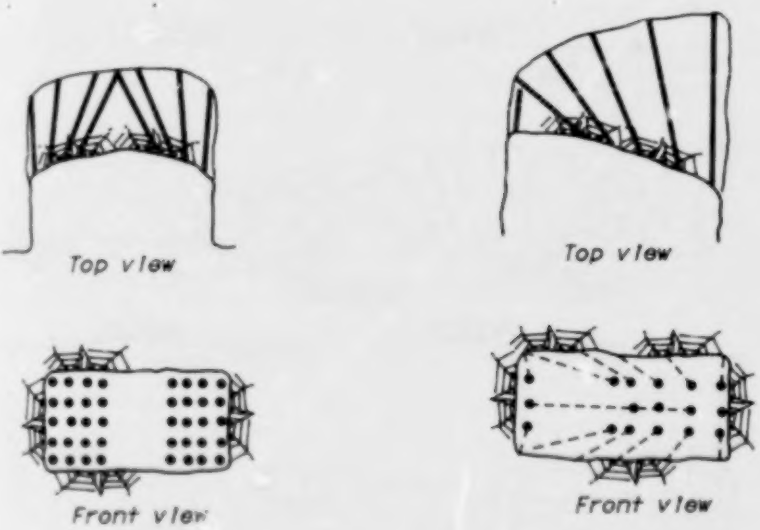


Figure 18-19. – Nomenclature for blastholes in a heading round.

lifters at the bottom of the heading. Unless a controlled blasting technique is used (discussed below) the spacing between these perimeter holes is about 20 to 25 blasthole diameters. Figure 18-20 shows two typical angled cut blast rounds. After the initial wedge of rock is extracted by the cut, the angles of the subsequent blastholes are reduced progressively until the perimeter holes are parallel to the heading or looking slightly outward. In designing burden and spacing dimensions for angled cut blast rounds, the location of the bottom of the hole is considered rather than the collar.

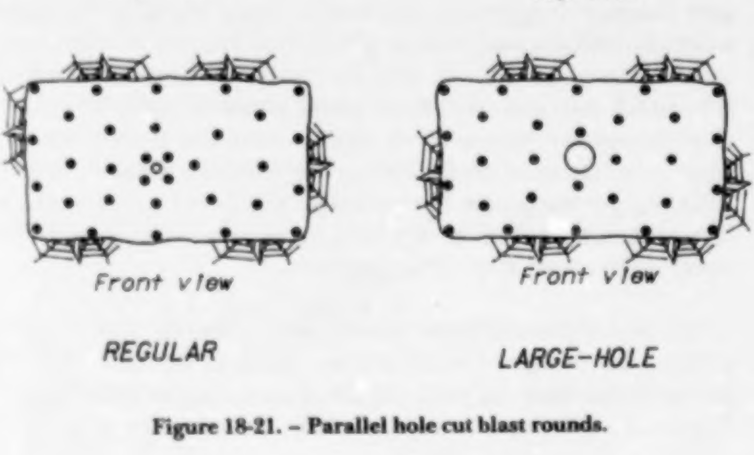
Figure 18-21 shows two typical parallel hole cut blast rounds. These rounds are simpler to drill than angled cut rounds. Once the central opening has been established, the round resembles a bench round turned on its side. Figure 18-22 shows a comparison of typical muckpiles obtained from V-cut and burn-cut blast rounds. Burn cuts give more uniform fragmentation and a more compact muckpile than V-cuts, where the muckpile is more spread out and variable in fragmentation. Powder factors and the amount of drilling required are higher for burn cuts.



V-CUT ROUND

SLABBING ROUND

Figure 18-20. – Angled cut blast rounds.



REGULAR

LARGE-HOLE

Figure 18-21. – Parallel hole cut blast rounds.

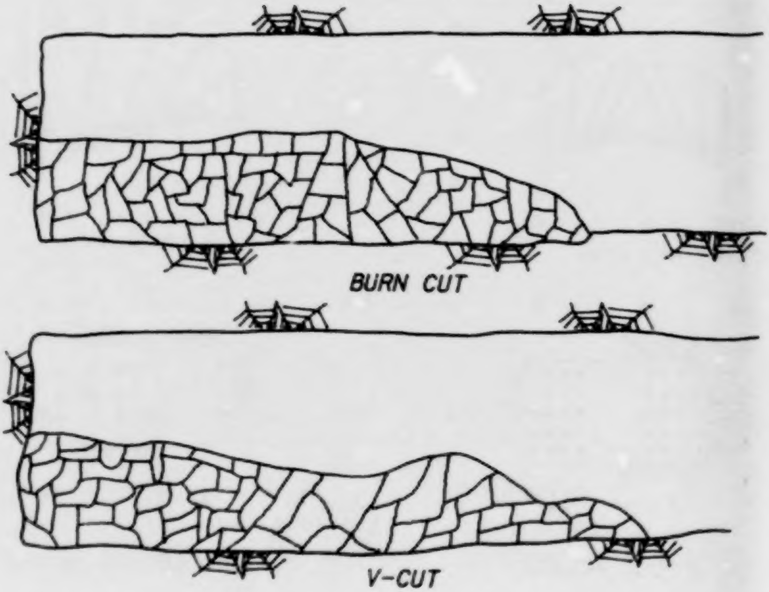


Figure 18-22. – Fragmentation and shape of muckpile as a function of type of cut.

Delays

Two series of delays are available for underground blasting; millisecond delays, which are the same as those used in surface blasting, and slow, or tunnel delays. The choice of delay depends on the size of the heading being blasted and on the fragmentation and type of muckpile desired. Slow delays give coarser fragmentation and a more compact muckpile whereas millisecond delays give finer fragmentation and a looser muckpile (fig. 18-23). In small headings where space is limited, particularly when using parallel hole cut rounds, slow delays are necessary to assure that the rock from each blasthole has time to be ejected before the next hole fires. Where a compromise between the results of millisecond delays and slow delays is desired, some operators use millisecond delays and skip delay periods.

In an underground blast round, it is essential that the delay pattern be designed so that each hole, at its time of firing, has a good free face to which it can displace its burden. Figure 18-24 shows a typical delay pattern for a burn cut

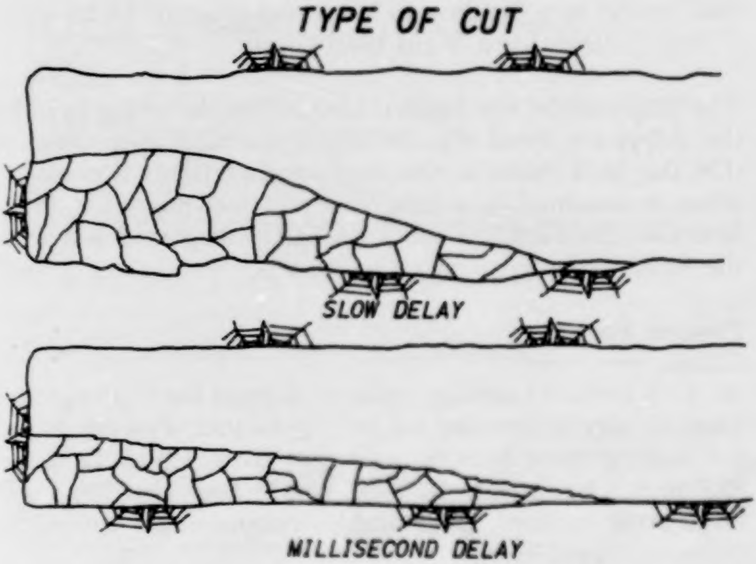


Figure 18-23. – Fragmentation and shape of muckpile as a function of delay.

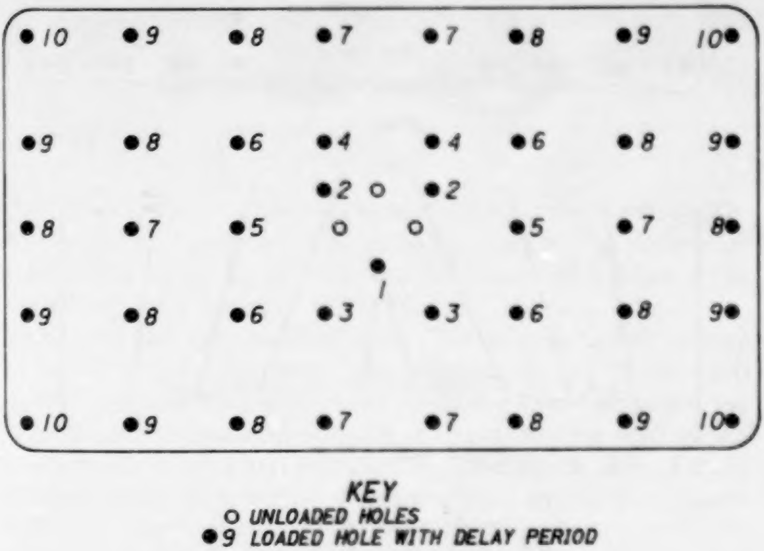


Figure 18-24. – Typical burn cut blast round delay pattern (numbers on loaded holes show delay in milliseconds).

blast round in a heading in hard rock. Figure 18-25 shows a delay pattern for a V-cut blast round.

The shape of the muckpile is affected by the order in which the delays are fired (fig. 18-26). If the blast is designed so that the back holes at the roof are fired last, a cascading effect is obtained, resulting in a compact muckpile. If the lifters are fired last, the muckpile will be displaced away from the face.

Powder Factor

As with surface blasting, powder factors for underground blasting vary depending on several factors. Powder factors for underground blasting may vary from 1.5 to 12 lb/yd^3 (0.7 to 5.5 kg/m^3). Soft, light weight rock, headings with large cross sections, large blastholes, and angle cut rounds

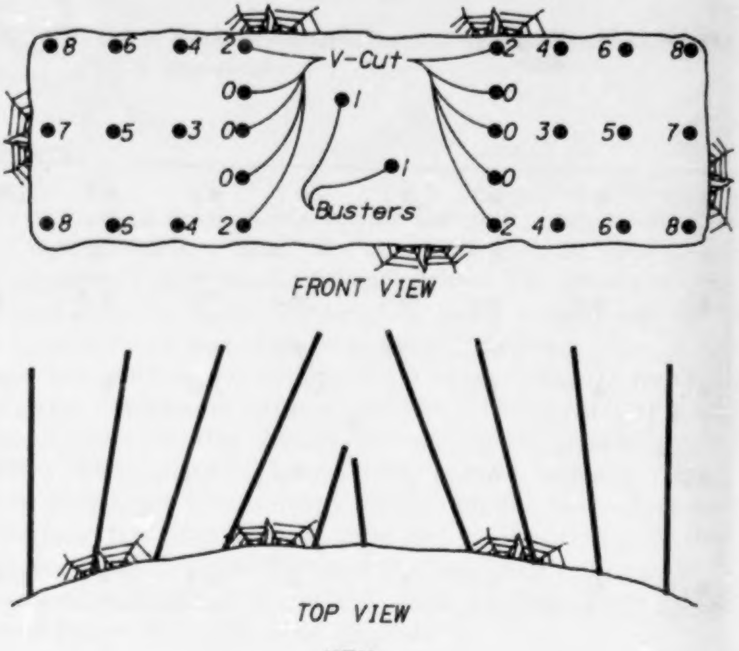
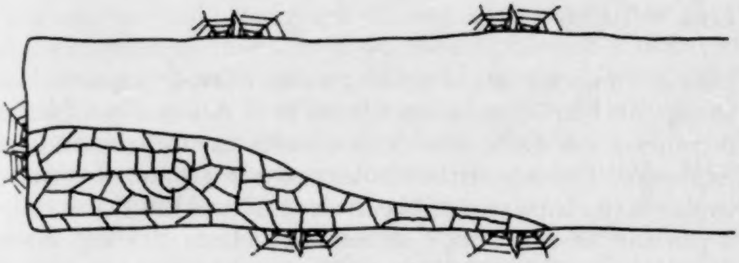
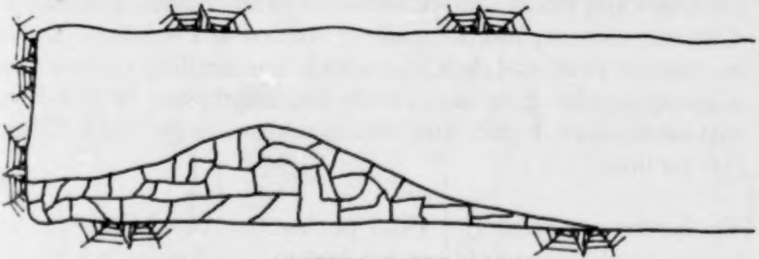


Figure 18-25. – Typical V-cut blast round delay pattern (numbers on loaded holes show delay in milliseconds).



BACK HOLES FIRED LAST



LIFTERS FIRED LAST

Figure 18-26. – Shape of muckpile as a function of firing order.

all tend to require lower powder factors than hard, dense rock, small headings, small blastholes, and parallel hole cuts.

Controlled Blasting Techniques

General

The term controlled blasting is used to describe several techniques that will prevent damage to the rock at the perimeter of the excavation by preventing the force of a blast from continuing into the side walls. Normal blasting propagates cracks into the surrounding rock. These cracks can reduce the stability of the opening. The purpose of controlled blasting is to reduce this perimeter cracking and thus increase stability of the final slope. Much of the following discussions on controlled blasting techniques have been determined through years of on-the-job testing and evaluation. Once again, the result of controlled blasting are a function of the geology, specifically the number and orientation of joint and fracture planes and the quality of the final rock surface that is required.

Line Drilling

Line drilling consists of drilling a row of closely spaced holes along the final excavation limits. It is not really a blasting technique since the line-drilled holes are not loaded with explosive. The line-drilled holes provide a plane of weakness to which the final row of blastholes can break and also reflect a portion of the blast's stress wave. Line drilling is used mostly in small blasting operations and involves small holes in the range of 2- to 3-inches (50-75 millimeters) in diameter. Line drilling holes are spaced (center to center) two to four diameters apart, but are closely spaced at the corners. The maximum practical depth to which line drilling can be done is governed by how accurately the alignment of the holes can be held at depth, and this is seldom more than 30 feet (10 meters).

To further protect the final perimeter, the blastholes adjacent to the line drill are spaced more closely, are loaded more lightly than the rest of the blast, and using deck charges as necessary. Best results are obtained in a homogeneous rock with few joints or bedding planes, or when the holes are aligned with a major joint plane. Line drilling sometimes is performed in conjunction with presplitting; where the corners are line drilled and the remainder of the perimeter is presplit.

The use of line drilling is limited to jobs where even a light load of explosives in the perimeter holes would cause unacceptable damage. The results of line drilling are often unpredictable, the cost of drilling is high, and the results are heavily dependent on the accuracy of drilling.

Presplitting

Presplitting, sometimes called preshearing, is similar to line drilling except that the holes are drilled slightly farther apart and are loaded very lightly. Presplit holes are fired before any of the adjacent main blastholes. Although the specific theory of presplitting is in dispute, the light explosive charges propagate a crack between the holes. In badly fractured rock, unloaded guide holes may be drilled between the loaded holes. The light powder load may be obtained by using specially designed slender cartridges, partial or whole cartridges taped to a detonating cord downline, an explosive cut from a continuous reel, or even heavy grain detonating cord. A heavier charge of tamped cartridges is used in the bottom few feet of hole. Figure 18-27 shows three types of blasthole loads used for presplitting. Many operators now use 3/4-or 7/8-in by 2-ft (19 or 22 millimeters by 0.6 meter) cartridges connected with couplers. Manufacturers now produce continuous small-diameter, long-tubular water gel columns for loading presplit holes. The diameter of these continuous tubular columns usually

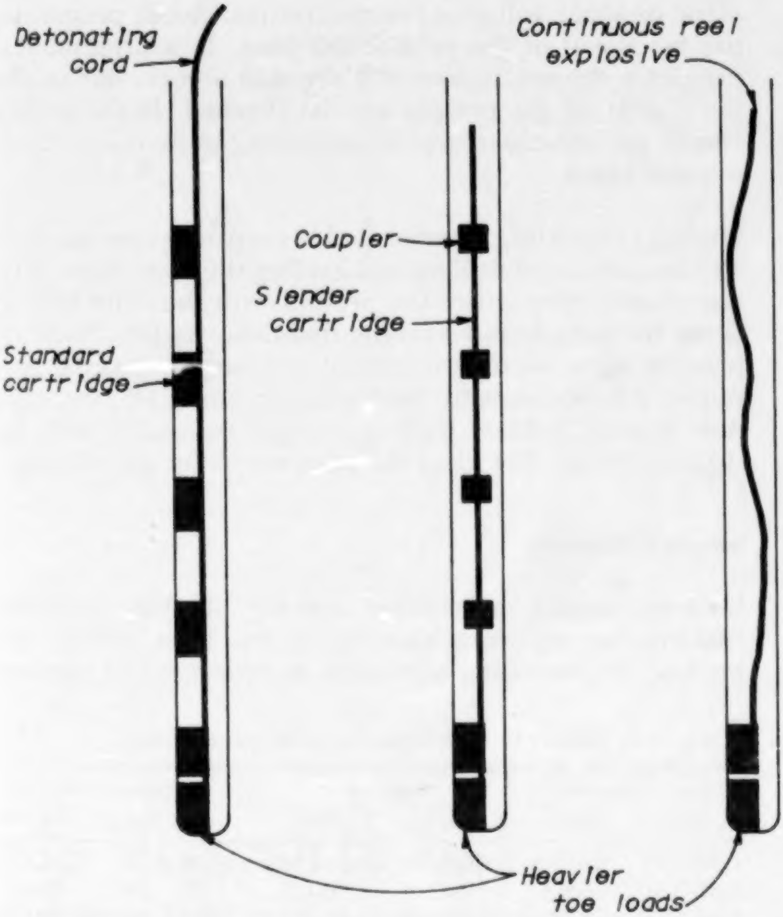


Figure 18-27. – Typical presplit blasthole loading.

is 1-inch (25 millimeters) and come with a built-in downline. They can be loaded easily in rough and inclined holes. Thus, the continuous column presplit explosives produce increased loading rates and reduced labor costs.

It is desirable to stem completely around and between the cartridges in the blasthole. It is desirable, although not essential, to fire all the presplit holes on the same delay period in advance of the main blast. The maximum depth for a single presplit is limited by the accuracy of the drillholes, and is usually about 50 ft (15m), but depths between 20 and 40 feet (6 and 12 meters) are recommended. A deviation of greater than 6 inches (152 milimeters) from the desired plane or shear will give inferior results. Avoid presplitting too far ahead of the production blast. It is preferable to presplit a shorter section and dig that section out so that the quality of the presplit can be checked. If the presplit results are unsatisfactory, adjustments can be made in subsequent blasts.

Usually presplitting is performed in a separate operation and well in advance of drilling and loading the main blast. Some operators prefer to fire the presplit with the main blast by firing the presplit holes on the first delay period. Although presplitting is usually thought of as a surface blasting technique, it is occasionally used underground. The increased hole spacing reduces drilling costs as compared with line drilling. Table 18-4 gives the parameters for presplitting.

Smooth Blasting

Smooth blasting, also called contour blasting, perimeter blasting, or sculpture blasting, is the most widely used method of controlling overbreak in underground openings

Table 18-4. – Parameters for presplitting.

Hole diameter		Spacing		Explosive charge,	
(in)	(mm)	(ft)	(m)	(lb/ft)	(kg/m)
1.50-1.75	38-44	1.00-1.50	0.3 -0.46	0.08-0.25	0.03-0.1
2.00-2.50	50-64	1.50-2.00	.46-0.6	.08- .25	0.03-0.1
3.00-3.50	75-90	1.50-3.00	0.6 -1.	.13- .50	0.05-0.23
4.00	100	2.00-4.00	0.6 -1.2	.25- .75	0.23-0.34

such as drifts and stopes (benches). Smooth blasting is similar to presplitting in that an additional row of holes is drilled at the perimeter of the excavation. These holes contain light loads and are more closely spaced than the other holes in the round (fig. 18-28). The light powder load usually is accomplished by "string loading" continuously (loaded end to end) slender cartridges or using continuous reel explosive as shown in figure 18-27. Unlike presplitting, the smooth blast holes are fired after the main blast. Usually this is accomplished by loading and connecting the entire round and firing the perimeter holes one delay later than the last

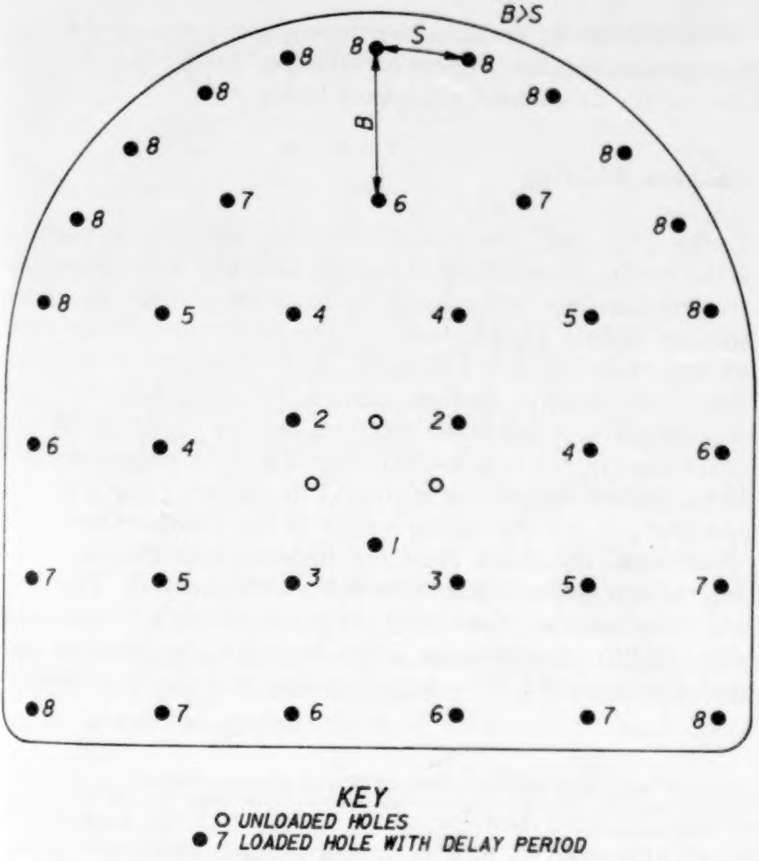


Figure 18-28. – **Typical smooth blasting pattern (Burden, B, is larger than spacing, S). Numbers on loaded holes show delay, in milliseconds.**

hole in the round. As a first approximation, the burden on the perimeter holes should be approximately 1.5 times the spacing. Table 18-5 gives the parameters for smooth blasting.

For the smooth wall blasting technique some operators have compromised by slightly reducing the spacing of their perimeter holes, as compared with standard design, and "string load" regular cartridges of explosive. It is recommended procedure to seal the explosive column with a tamping plug, clay plug, or other types of stemming to prevent the string-loaded charges from being extracted from the hole by charges on earlier delays.

Smooth blasting reduces overbreak and reduces the need for ground support. These advantages usually outweigh the cost of the additional perimeter holes.

Cushion Blasting

Cushion blasting, also called trimming, slabbing or slashing, is the surface equivalent of smooth blasting. Like other controlled blasting techniques, it involves a row of closely spaced, lightly loaded holes at the perimeter of the excavation. Holes up to 6-1/2-inch (165 millimeters) in diameter have been used in cushion blasting. Drilling accuracy with this larger size borehole permits depths of up to 90 feet (27.4 meters) for cushion blasting. After the explosives have been loaded, stemming is placed in the void space around the charges, for the entire length of the column. Stemming "cushions" the shock from the finished wall thus, minimizing the stresses and fractures in the finished wall. The cushion blast holes are fired after the main excavation is removed (fig. 18-29). A minimum delay between the cushion blast holes is desirable. The same loading techniques that apply

Table 18-5. – Parameters for smooth blasting.

Hole diameter		Spacing		Burden		Explosive charge	
(in)	(mm)	(ft)	(m)	(ft)	(m)	(lb/ft)	(kg/m)
1.50-1.75	38-44	2.00	0.6	3.00	1	0.12-0.25	0.05-0.55
2.0	50	2.50	.75	3.50	1.06	.12- .25	0.05-0.55

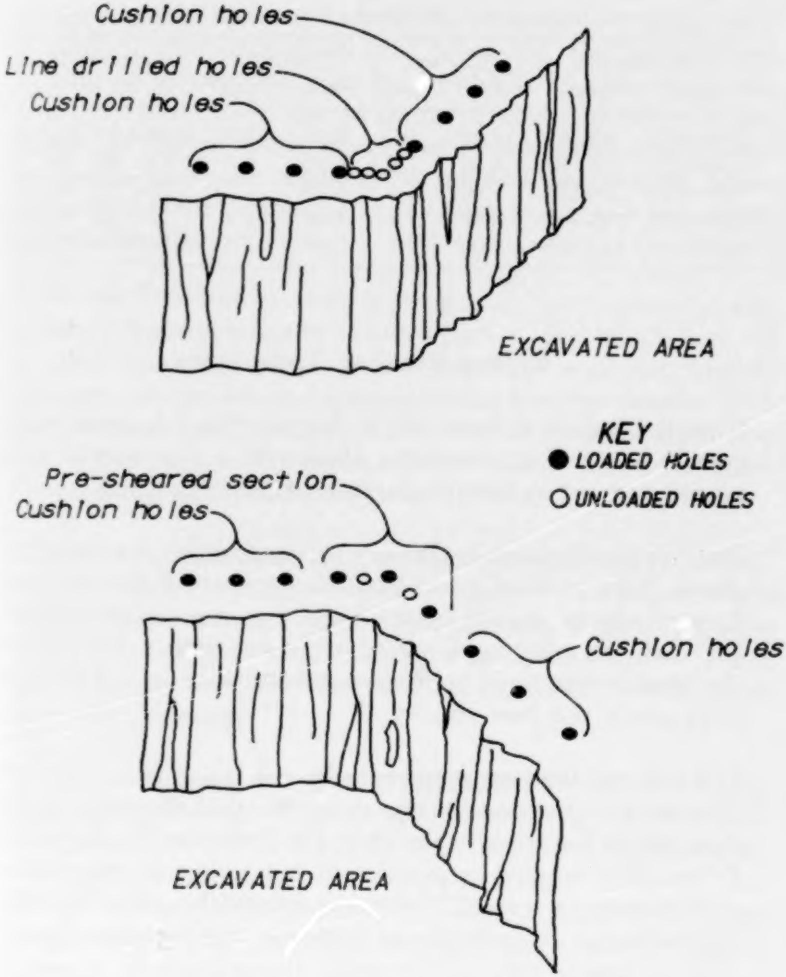


Figure 18-29. – Cushion blasting techniques.

to presplitting are used with cushion blasting. The burden on the cushion holes should always be less than the width of the berm being removed.

The large diameter holes associated with cushion blasting result in larger spacings as compared with presplitting, thus reducing drilling costs. Better results can be obtained in poorly lithified and weathered formations than with presplitting, and the larger holes permit better alignment at depth. Table 18-6 gives parameters for cushion blasting.

Table 18-6. – Parameters for cushion blasting.

Hole diameter		Spacing		Burden		Explosive charge	
(inch)	(mm)	(feet)	(m)	(feet)	(m)	lb/ft)	(kg/m)
2.00-2.50	50- 64	3.00	1	4.00	1.2	0.08-0.25	0.03-0.1
3.00-3.50	75- 90	4.00	1.2	5.00	1.5	.13- .50	0.05-0.2
4.00-4.50	100-114	5.00	1.5	6.00	1.8	.25- .75	0.1 -0.3
5.00-5.50	127-140	6.00	1.8	7.00	2.1	.75-1.00	0.3 -0.45
6.00-6.50	152-165	7.00	2.1	9.00	2.7	1.00-1.50	0.45-0.7

Riprap Blasting Techniques

Riprap blasting follows the rules for blast designs as discussed in previous sections. However, a few special techniques can aid in the production of quality riprap.

Powder distribution is the key to satisfactory results. If the above principles of good blast designs are followed, satisfactory results should be achieved. As stressed throughout this chapter, blasting is more of an art than a science and the blast design must be monitored continually and changed to produce the best results.

Full column loading appears to be the best for initial shots. The starting burden for riprap production should be larger than predicted from table 18-1. For instance, if a burden of 7 feet (2.1 meters) is predicted, a starting burden of approximately 9 feet (2.7 meters) should be tried. Further adjustments can be made to optimize the breakage.

In typical quarry blasting, a spacing of 1.5 times the burden is a good first estimate. However, for riprap, the spacing should be about equal to the burden, but not smaller than the burden. Either a square or a staggered drill pattern should be used. The square pattern often gives a coarser product but also may give more erratic toe conditions. Where possible, rows of blastholes should be perpendicular to the major vertical plane of weakness, such as the primary vertical joint set.

If a reasonably well graded riprap is specified it will be necessary to put off blasts on a test or trial basis. The product should be analyzed for gradation and test blasts made and gradations checked until the specifications have been met. If insufficient coarse product is produced, the burden and spacing of subsequent rounds should be increased by one foot per round until the amounts of coarse product is adequate. If toe problems occur before the amount of coarse product is adequate, reduce the burden and spacing again and increase the stemming or try deck loading in the upper part of the lift.

If too much coarse product is produced, determine whether it comes from the top or bottom part of the bench face. If it comes from the bottom or is generally well-distributed, decrease the burden and spacing in one foot increments until the oversize is controlled. If the oversize comes from the top, try using satellite holes (short, smaller diameter holes between the main blastholes, fig. 18-4) or less stemming.

It is essential that each blast be laid out accurately, drilled, and loaded so that there is a known baseline to adjust from if early results are not good. The keeping of good records is essential for later adjustments to the blast design. Single row firing, at least for the early shots, also simplifies blast pattern adjustments.

In dry conditions, AN-FO (Ammonium Nitrate-Fuel Oil, dry type explosive) will work well; however, good, fast, bottom primer should be used. In wet conditions, an emulsion, water gel, slurry or gelatin dynamite should be used. The bottom of the blasthole should be primed. Excessive orange smoke from a blast indicates the need for a water resistant product, or for a better proportional mix of the AN-FO.

Bibliography

[1] Dick, R. A., Fletcher, L. R., and Andrea, D. V., *Explosives and Blasting Procedures Manual*. Bureau of Mines Information Circular 8925, pp. 57-74, 1987.

[2] E. I. du Pont de Nemours & Co., Inc. (Wilmington, DE). *Blaster's Handbook*. 16th ed., pp. 494, 1978.

[3] Ash, R. L., The Mechanics of Rock Breakage, Parts I, II, III, and IV. *Pit and Quarry*, v. 56, No. 2, August 1963,

pp. 98-112; No. 3, September 1963, pp. 118.123; No. 4, October 1963, pp. 126-131; No. 5, November, 1963, pp. 109-111, 114-118.

[4] Pugleise, J. M., Designing Blast Patterns Using Empirical Formulas. BuMines IC 8550, pp. 33, 1972.

[5] Dick, R. A., and J. J. Olson, Choosing the Proper Borehole Size for Bench Blasting. *Min. Eng.*, v. 24, No. 3, pp. 41-45, March 1972.

[6] Andrews, A. B., Design of Blasts. Emphasis on Blasting. Ensign Bickford Co. (Simsbury CN), pp. 1 and 4, Spring 1980.

[7] Schmidt, R. L., R. J. Morrell, D. H. Irby, and R. A. Dick. Application of Large-Hole Burn Cut in Room-and-Pillar Mining. BuMines RI 7994, pp. 25, 1975.

Glossary of Terms Used in Explosives and Blasting[1]

Acoustical impedance.—The mathematical expression characterizing a material as to its energy transfer properties. The product of its unit density and its sonic velocity.

Adobe charge.—*See* mud cap.

Airblast.—An airborne shock wave resulting from the detonation of explosives. May be caused by burden movement or the release of expanding gas into the air. Airblast may or may not be audible.

Airdox.—A system that uses 10,000 lb/in^2 compressed air to break undercut coal. Airdox will not ignite a gassy or dusty atmosphere.

Aluminum.—A metal commonly used as a fuel or sensitizing agent in explosives and blasting agents. Normally used in finely divided particle or flake form.

---

[1] Additional definitions can be found in Institute of Makers of Explosives Pamphlet No. 12, Glossary of Industry Terms, September 1981, pp. 28.

American Table of Distance.—A quantity-distance table published by Institute of Makers of Explosives (IME) as pamphlet No. 2, which specifies safe explosive storage distances from inhabited buildings, public highways, passenger railways and other stored explosive materials.

Ammonium nitrate (AN).—The mostly commonly used oxidizer in explosives and blasting agents. Its formula is NH_4NO_3.

AN-FO.—An explosive material consisting of ammonium nitrate and fuel oil. The mostly commonly used blasting agent.

Axial priming.—A system for priming blasting agents in which a core of priming materials extends through most or all of the blasting agent charge length.

Back break.—Rock broken beyond the limits of the last row of holes.

Back holes.—The top holes in a tunnel or drift round.

Base charge.—The main explosive charge in a detonator.

BATF.—Bureau of Alcohol, Tobacco and Firearms, U.S. Department of the Treasury, which enforces explosives control and security regulations.

Beds or bedding.—Layers of sedimentary rock, usually separated by a surface of discontinuity. As a rule, the rock can be readily separated along these planes.

Bench.—The horizontal ledge in a quarry face along which holes are drilled vertically. Benching is the process of excavating whereby terraces or ledges are worked in a stepped sequence.

Binary explosive.—An explosive based on two nonexplosive ingredients, such as nitromethane and ammonium nitrate, which are shipped and stored separately and mixed at the jobsite to form a high explosive.

Black powder.—A low explosive consisting of sodium or potassium nitrate, carbon, and sulfur. Black powder is seldom used today because of its low energy, poor fume quality, and extreme sensitivity to sparks.

Blast.—The detonation of explosives to break rock.

Blast area.—The area near a blast within the influence of flying rock missiles, or concussion.

Blaster.—A qualified person in charge of a blast. Also, a person (blaster-in-charge) who has passed a test, approved by OSM (Office of Surface Mining), which certifies his or her qualifications to supervise blasting activities.

Blasters' galvanometer; blasters' multimeter.—*See* galvanometer; multimeter.

Blasthole.—A hole drilled in rock or other material for the placement of explosives.

Blasting agent.—An explosive that meets prescribed criteria for insensitivity to initiation. For storage, any material or mixture consisting of a fuel and oxidizer, intended for blasting, not otherwise defined as an explosive, provided that the finished produce, as mixed and packaged for use or shipment, cannot be detonated by means of a No. 8 test blasting cap when unconfined (BATF). For transportation, a material designed for blasting which has been tested in accordance with CFR (Code of Federal Regulations) Title 49, Section 173.14a, and found to be so insensitive that there is very little probability of accidental initiation to explosion or transition from deflagration to detonation (DOT [Department of Transportation]).

Blasting cap.—A detonator that is initiated by safety fuse (MSHA [Mine Safety & Health Administration]). *See also* detonator.

Blasting circuit.—The electrical circuit used to fire one or more electric blasting caps.

Blasting crew.—A group of persons whose purpose is to load explosive charges.

Blasting machine.—Any machine built expressly for the purpose of energizing electric blasting caps or other types of initiator.

Blasting mat.—*See* mat.

Blasting switch.—A switch used to connect a power source to a blasting circuit.

Blistering.—*See* mud cap.

Blockhole.—A hole drilled into a boulder to allow the placement of a small charge to break the boulder.

Booster.—A unit of explosive or blasting agent used for perpetuating or intensifying an explosive reaction. A booster does not contain an initiating device but is often cap sensitive.

Bootleg.—That portion of a borehole that remains relatively intact after having been charged with explosive and fired. A bootleg may contain unfired explosive and should be considered hazardous.

Borehole (blasthole).—A drilled hole, usually in rock, into which explosives are loaded for blasting.

Borehole pressure.—The pressure which the hot gases of detonation exert on the borehole wall. Borehole pressure is primarily a function of the density of the explosive and the heat of explosion.

Bridge wire.—A very fine filament wire imbedded in the ignition element of an electric blasting cap. An electric current passing through the wire causes a sudden heat rise, causing the ignition element to be ignited.

Brisance.—A property of an explosive roughly equivalent to detonation velocity. An explosive with a high detonation velocity has high brisance.

Bubble energy.—The expanding gas energy of an explosive, as measured in an underwater test.

Bulk mix.—A mass of explosive material prepared for use without packaging.

Bulk strength.—The strength of an explosive per unit volume.

Bulldoze.—*See* mud cap.

Burden.—The distance for an explosive charge to the nearest free or open face. Technically, there may be apparent burden and a true burden, the latter being measured in the direction in which displacement of broken rock will occur following firing of the explosive charge. Also, the amount of material to be blasted by a given hole, given in tons or cubic yards.

Burn cut.—A parallel hole cut employing several closely spaced blastholes. Not all of the holes are loaded with explosive. The cut creates a cylindrical opening by shattering the rock.

Bus wires.—The two wires, joined to the connecting wire, to which the leg wires of the electric caps are connected in a parallel circuit. Each leg wire if each cap is connected to a different bus wire. In a series-in-parallel circuit, each end of each series is connected to a different bus wire.

Butt.—*See* bootleg.

Cap.—*See* detonator.

Capped fuse.—A length of safety fuse to which a blasting cap has been attached.

Capped primer.—A package or cartridge of cap-sensitive explosive which is specifically designed to transmit detonation to other explosives and which contains a detonator (MSHA).

Cap sensitivity.—The sensitivity of an explosive to initiation, expressed in terms of an IME No. 8 test detonator or a fraction thereof.

Carbon monoxide.—A poisonous gas created by detonating explosive materials. Excessive carbon monoxide is caused by an inadequate amount of oxygen in the explosive mixture (excessive fuel).

Cardox.—A system that uses a cartridge filled with liquid carbon dioxide, which, when initiated by a mixture of potassium perchlorate and charcoal, creates a pressure adequate to break undercut coal.

Cartridge.—A rigid or semirigid container of explosive or blasting agent of a specified length or diameter.

Cartridge count.—The number of 1-1/4- by 8-inch (32 x 203 millimeters) cartridges of explosives per 50-lb (22.7 kg) case.

Cartridge strength.—A rating that compares a given volume of explosive with an equivalent volume of straight nitroglycerin dynamite, expressed as a percentage.

Cast primer.—A cast unit of explosive, usually pentolite or composition B, commonly used to initiate detonation in a blasting agent.

Chambering.—The process of enlarging a portion of blasthole (usually the bottom) by firing a series of small explosive charges. Chambering can also be done by mechanical or thermal methods.

Chapman-Jougeut (C-J) plane.—In a detonating explosive column, the plane that defines the rear boundary of the primary reaction zone.

Circuit tester.—*See* galvanometer; multimeter.

Class A explosive.—Defined by the U.S. Department of Transportation (DOT) as an explosive that possesses detonating or otherwise maximum hazard; such as, but not limited to, dynamite, nitroglycerin, lead azide, black powder, blasting caps, and detonating primers.

Class B explosive.—Defined by DOT as an explosive that possesses flammable hazard; such as, but not limited to, propellant explosives, photographic flash powders, and some special fireworks.

Class C explosive.—Defined by DOT as an explosive that contains Class A or Class B explosives, or both, as components but in restricted quantities. For example, blasting caps or electric blasting caps in lots of less than 1,000.

Collar.—The mouth or opening of a borehole or shaft. To collar in drilling means the act of starting a borehole.

Collar distance.—The distance from the top of the powder column to the collar of the blasthole, usually filled with stemming.

Column charge.—A long, continuous charge of explosive or blasting agent in a borehole.

Commercial explosives.—Explosives designed and used for commercial or industrial, rather than military applications.

Composition B.—A mixture of RDX and TNT which, when cast, has a density of 1.65 g/cm^3 and a velocity of 25,000 feet per second (7622 m/s). It is useful as a primer for blasting agents.

Condenser-discharge blasting machine.—A blasting machine that uses batteries or magnets to energize one or more condensers (capacitors) whose stored energy is released into a blasting circuit.

Confined detonation velocity.—The detonation velocity of an explosive or blasting agent under confinement, such as in a borehole.

Connecting wire.—A wire, smaller in gage than the lead wire, used in a blasting circuit to connect the cap circuit with the lead wire or to extend leg wires from one borehole to another. Usually considered expendable.

Connector.—*See* MS connector.

Controlled blasting.—Techniques used to control overbreak and produce a competent final excavation wall. *See* line drilling, presplitting, smooth blasting, and cushion blasting.

Cordeau detonant fuse.—A term used to define detonating cord.

Cornish cut.—*See* parallel hole cut.

Coromant cut.—*See* parallel hole cut.

Coupling.—The degree to which an explosive fills the borehole. Bulk loaded explosives are completely coupled. Untamped cartridges are decoupled. Also, capacitive and inductive coupling from powerlines, which may be introduced into an electric blasting circuit.

Coyote blasting.—The practice of driving tunnels horizontally into a rock face at the foot of the shot. Explosives are loaded into these tunnels. Coyote blasting is used where it is impractical to drill vertically.

Critical diameter.—For any explosive, the minimum diameter for propagation of a stable detonation. Critical diameter is affected by confinement, temperature, and pressure on the explosive.

Crosslinking agent.—The final ingredient added to a water gel or slurry, causing it to change from a liquid to a gel.

Current limiting device.—A device used to prevent arcing in electric blasting caps by limiting the amount or duration of current flow. Also used in a blasters' galvanometer or multimeter to assure a safe current output.

Cushion blasting.—A surface blasting technique used to produce competent slopes. The cushion holes, fired after the main charge, have a reduced spacing and employ decoupled charges.

Cushion stick.—A cartridge of explosive loaded into a small-diameter borehole before the primer. The use of a cushion stick is not generally recommended because of possible resulting bootlegs.

Cut.—An arrangement of holes used in underground mining and tunnel blasting to provide a free face to which the remainder of the round can break. Also the opening created by the cut holes.

Cutoffs.—A portion of a column of explosives that has failed to detonate owing to bridging or a shifting of the rock formation, often due to a improper delay system. Also a cessation of detonation in detonating cord.

Dead pressing.—Desensitization of an explosive, caused by pressurization. Tiny air bubbles, required for sensitivity, are literally squeezed from the mixture.

Decibel.—The unit of sound pressure commonly used to measure airblast from explosives. The decibel scale is logarithmic.

Deck.—A small charge or portion of a blasthole loaded with explosives which is separated from other charges by stemming or an air cushion.

Decoupling.—The use of cartridged products significantly smaller in diameter than the borehole. Decoupled charges are normally not used except in cushion blasting, smooth blasting, presplitting, and other situations where crushing is undesirable.

Deflagration.—A subsonic but extremely rapid explosive reaction accompanied by gas formation and borehole pressure, but without shock.

Delay blasting.—The use of delay detonators or connectors that cause separate charges to detonate at different times, rather than simultaneously.

Delay connector.—A nonelectric, short-interval delay device for use in delaying blasts that are initiated by detonating cord.

Delay detonator.—A detonator, either electric or nonelectric, with a built-in element that creates a delay between the input of energy and the explosion of the detonator.

Delay electric blasting cap.—An electric blasting cap with a built-in delay that delays cap detonation in predetermined time intervals, from milliseconds up to a second or more, between successive delays.

Delay element.—That portion of a blasting cap which causes a delay between the instant of application of energy to the cap and the time of detonation of the base charge of the cap.

Density.—The weight per unit volume of explosive, expressed as cartridge count or grams per cubic centimeter. *See* loading density.

Department of Transportation (DOT).—A Federal agency that regulates safety in interstate shipping of explosives and other hazardous materials.

Detaline System.—A nonelectric system for initiating blasting caps in which the energy is transmitted through the circuit by means of a low-energy detonating cord.

Detonating cord.—A plastic-covered core of high-velocity explosive, usually PETN, used to detonate charges of explosives. The plastic covering, in turn, is covered with various combinations of textiles and waterproofing.

Detonation.—A supersonic explosive reaction that propagates a shock wave through the explosive accompanied by a chemical reaction that furnishes energy to sustain the shock wave propagation in a stable manner. Detonation creates both a detonation pressure and a borehole pressure.

Detonation pressure.—The head-on pressure created by the detonation proceeding down the explosive column. Detonation pressure is a function of the explosive's density and the square of its velocity.

Detonation velocity.—*See* velocity.

Detonator.—Any device containing a detonating charge that is used to initiate an explosive. Includes, but is not limited to, blasting caps, electric blasting caps, and nonelectric instantaneous or delay blasting caps.

Ditch blasting.—*See* propagation blasting.

DOT.—*See* Department of Transportation.

Downline.—The line of detonating cord in the borehole which transmits energy from the trunkline down the hole to the primer.

Drilling pattern.—*See* pattern.

Drop ball.—Known also as a headache ball. An iron or steel weight held on a wire rope which is dropped from a height onto large boulders for the purpose of breaking them into smaller fragments.

Dynamite.—The high explosive invented by Alfred Nobel. Any high explosive in which the sensitizer is nitroglycerin or a similar explosive oil.

Echelon pattern.—A delay pattern that causes the true burden, at the time of detonation, to be an oblique angle from the original free face.

Electric blasting cap.—A blasting cap designed to be initiated by an electric current.

Electric storm.—An atmospheric disturbance of intense electrical activity presenting a hazard in all blasting activities.

Emulsion.—An explosive material containing substantial amounts of oxidizers dissolved in water droplets surrounded by an immiscible fuel. Similar to a slurry in some respects.

Exploding bridge wire (EBW).—A wire that explodes upon application of current. It takes the place of the primary explosive in an electric detonator. An exploding bridge wire detonator is an electric detonator that employs an exploding bridge wire rather than a primary explosive. An exploding bridge wire detonator functions instantaneously.

Explosion.—A thermochemical process in which mixtures of gases, solids, or liquids react with the almost instantaneous formation of gaseous pressures and sudden heat release.

Explosion pressure.—*See* borehole pressure.

Explosive.—Any chemical mixture that reacts at high velocity to liberate gas and heat, causing very high pressures. BATF classifications include high explosives and low explosives. Also, any substance classified as an explosive by DOT.

Explosive materials.—A term which includes, but is not necessarily limited to, dynamite and other high explosives, slurries, water gels, emulsions, blasting agents, black powder, pellet powder, initiating explosives, detonators, safety fuses, squibs, detonating cord, igniter cord, and igniters.

Extra dynamite.—Also called ammonia dynamite, a dynamite that derives the major portion of its energy from ammonium nitrate.

Extraneous electricity.—Electrical energy, other than actual firing current, which may be a hazard with electric blasting caps. Includes stray current, static electricity, lightning, radio-frequency energy, and capacitive or inductive coupling.

Face.—A rock surface exposed to air. Also called a free face, a face provides the rock with room to expand upon fragmentation.

Firing current.—Electric current purposely introduced into a blasting circuit for the purpose of initiation. Also, the amount of current required to activate an electric blasting cap.

Firing line.—A line, often permanent, extending from the firing location to the electric blasting cap circuit. Also called lead wire.

Flash over.—Sympathetic detonation between explosive charges or between charged blastholes.

Flyrock.—Rock that is propelled through the air from a blast. Excessive flyrock may be caused by poor blast design or unexpected zones of weakness in the rock.

Fracturing.—The breaking of rock with or without movement of the broken pieces.

Fragmentation.—The extent to which a rock is broken into pieces by blasting. Also the act of breaking rock.

Fuel.—An ingredient in an explosive which reacts with an oxidizer to form gaseous products of detonation.

Fuel oil.—The fuel, usually No. 2 diesel fuel, in AN-FO.

Fume classification.—An IME quantification of the amount of fumes generated by an explosive or blasting agent.

Fume quality.—A measure of the toxic fumes to be expected when a specific explosive is properly detonated. *See* fumes.

Fumes.—Noxious or poisonous gases liberated from a blast. May be due to a low fume quality explosive or inefficient detonation.

Fuse.—*See* safety fuse.

Fuse lighter.—A pyrotechnic device for rapid and dependable lighting of safety fuse.

Galvanometer.—(More properly called blasters' galvanometer.) A measuring instrument containing a silver chloride cell and/or a current limiting device which is used to measure resistance in an electric blasting circuit.

Only a device specifically identified as a blasting galvanometer or blasting multimeter should be used for this purpose.

Gap sensitivity.—A measure of the distance across which an explosive can propagate a detonation. The gap may be air or a defined solid material. Gap sensitivity is a measure of the likelihood of sympathetic propagation.

Gas detonation system.—A system for initiating caps in which the energy is transmitted through the circuit by means of a gas detonation inside a hollow plastic tube.

Gelatin.—An explosive or blasting agent that has a gelatinous consistency. The term is usually applied to a gelatin dynamite but may also be a water gel.

Gelatin dynamite.—A highly water-resistant dynamite with a gelatinous consistency.

Generator blasting machine.—A blasting machine operated by vigorously pushing down a rack bar or twisting a handle. Now largely replaced by condensor discharge blasting machines.

Grains.—A system of weight measurement in which 7,000 grains equal 1 pound.

Ground vibration.—A shaking of the ground caused by the elastic wave emanating from a blast. Excessive vibrations may cause damage to structures.

Hangfire.—The detonation of an explosive charge at a time after its designed firing time. A source of serious accidents.

Heading.—A horizontal excavation driven in an underground mine.

Hercudet.—*See* gas detonation system.

Hertz.—A term used to express the frequency of ground vibrations and airblast. One hertz is one cycle per second.

High explosive.—Any product used in blasting which is sensitive to a No. 8 test blasting cap and reacts at a speed faster than that of sound in the explosive medium. A classification used by BATF for explosive storage.

Highwall.—The bench, bluff, or ledge on the edge of a surface excavation. This term is most commonly used in coal strip mining.

Ignitacord.—A cordlike fuse that burns progressively along its length with an external flame at the zone of burning and is used for lighting a series of safety fuses in sequence. Burns with a spitting flame similar to a Fourth-of-July sparkler.

IME.—The Institute of Makers of Explosives. A trade organization dealing with the use of explosives, concerned with safety in manufacture, transportation, storage, handling, and use. The IME publishes a series of blasting safety pamphlets.

Initiation.—The act of detonating a high explosive by means of a cap, a mechanical device, or other means. Also the act of detonating the initiator.

Instantaneous detonator.—A detonator that contains no delay element.

Jet loader.—A system for loading AN-FO into small blastholes in which the AN-FO is drawn from a container by the venturi principle and blown into the hole at high velocity through a semiconductive loading hose.

Jumbo.—A machine designed to contain two or more mounted drilling units that may or may not be operated independently.

Kerf.—A slot cut in a coal or soft rock face by a mechanical cutter to provide a free face for blasting.

Lead wire.—The wire connecting the electrical power source with the leg wires or connecting wires of a blasting circuit. Also called firing line.

LEDC.—Low energy detonating cord, which may be used to initiate nonelectric blasting caps.

Leg wires.—Wires connected to the bridge wire of an electric blasting cap and extending from the waterproof plug. The opposite ends are used to connect the cap into a circuit.

Lifters.—The bottom holes in a tunnel or drift round.

Line drilling.—A method of overbreak control in which a series of very closely spaced holes are drilled at the perimeter of the excavation. These holes are not loaded with explosive.

Liquid oxygen explosive.—A high explosive made by soaking cartridges of carbonaceous materials in liquid oxygen. This explosive is rarely used today.

Loading density.—An expression of explosive density in terms of pounds of explosive per foot of charge of a specific diameter.

Loading factor.—*See* powder factor.

Loading pole.—A pole made of nonsparking material, used to push explosive cartridges into a borehole and to break and tightly pack the explosive cartridges into the hole.

Low explosive.—An explosive in which the speed of reaction is slower than the speed of sound, such as black powder. A classification used by BATF for explosive storage.

LOX.—*See* liquid oxygen explosive.

Magazine.—A building, structure, or container specially constructed for storing explosives, blasting agents, detonators, or other explosive materials.

Mat.—A covering placed over a shot to hold down flying material; usually made of woven wire cable, rope, or scrap tires.

Maximum firing current.—The highest current (amperage) recommended for the safe and effective performance of an electric blasting cap.

Metallized.—Sensitized or energized with finely divided metal flakes, powders, or granules, usually aluminum.

Michigan cut.—*See* parallel hole cut.

Microballoons.—Tiny hollow spheres of glass or plastic which are added to explosive materials to enhance sensitivity by assuring an adequate content of entrapped air.

Millisecond (ms).—The unit of measurement of short delay intervals, equal to 1/1000 of a second.

Millisecond delay caps.—Delay detonators that have built-in time delays of various lengths. The interval between the delays at the lower end of the series is usually 25 ms. The interval between delays at the upper end of the series may be 100 to 300 ms.

Minimum firing current.—The lowest current (amperage) that will initiate an electric blasting cap within a specified short interval of time.

Misfire.—A charge, or part of a charge, which for any reason has failed to fire as planned. All misfires are dangerous.

Monomethylaminenitrate.—A compound used to sensitize some water gels.

MS connector.—A device used as a delay in a detonating cord circuit connecting one hole in the circuit with another or one row of holes to other rows of holes.

MSHA.—The Mine Safety and Health Administration. An agency under the Department of Labor which enforces health and safety regulations in the mining industry.

Muckpile.—A pile of broken rock or dirt that is to be loaded for removal.

Mud cap.—Referred to also as adobe, bulldoze, blistering, or plaster shot. A charge of explosive fired in contact with the surface of a rock, usually covered with a quantity of mud, wet earth, or similar substance. No borehole is used.

Multimeter.—(More properly called blasters' multimeter.) A multipurpose test instrument used to check line voltages, firing currents, current leakage, stray currents, and other measurements pertinent to electric blasting. Only a meter specifically designated as a blasters' multimeter or blasters' galvanometer should be used to test electric blasting circuits.

National Fire Protection Association (NFPA).—An industry-government association that publishes standards for explosive material and ammonium nitrate.

Nitrocarbonitrate.—A classification once given to a blasting agent by DOT for shipping purposes. This term is not obsolete.

Nitrogen oxides.—Poisonous gases created by detonating explosive materials. Excessive nitrogen oxides may be caused by an excessive amount of oxygen in the explosive mixture (excessive oxidizer), or by inefficient detonation.

Nitroglycerin (NG).—The explosive oil originally used as the sensitizer in dynamites, represented by the formula $C_3H_5(ONO_2)_3$.

Nitromethane.—A liquid compound used as a fuel in two-component (binary) explosives and as rocket fuel.

Nitropropane.—A liquid fuel that can be combined with pulverized ammonium nitrate pills to make a dense blasting mixture.

Nitrostarch.—A solid explosive, similar to nitroglycerin in function, used as the base of "nonheadache" powders.

Nonel.—*See* shock tube system.

Nonelectric delay blasting cap.—A detonator with a delay element, capable of being initiated nonelectrically. *See* shock tube system; gas detonation system; Detaline System.

No. 8 test blasting cap.—*See* test blasting cap No. 8.

OSHA.—The Occupational Safety and Health Administration. An agency under the Department of Labor which enforces health and safety regulations in the construction industry, including blasting.

OSM.—The Office of Surface Mining Reclamation and Enforcement. An agency under the Department of Interior which enforces surface environmental regulations in the coal mining industry.

Overbreak.—Excessive breakage of rock beyond the desired excavation limit.

Overburden.—Worthless material lying on top of a deposit of useful materials. Overburden often refers to dirt or gravel, but can be rock, such as shale over limestone or shale and limestone over coal.

Overdrive.—The act of inducing a velocity higher than the steady state velocity in a powder column by the use of a powerful primer. Overdrive is a temporary phenomenon and the powder quickly assumes its steady state velocity.

Oxides of nitrogen.—*See* nitrogen oxides.

Oxidizer.—An ingredient in an explosive or blasting agent which supplies oxygen to combine with the fuel to form gaseous or solid products of detonation. Ammonium nitrate is the most common oxidizer used in commercial explosives.

Oxygen balance.—A state of equilibrium in a mixture of fuels and oxidizers at which the gaseous products of detonation are predominantly carbon dioxide, water vapor (steam), and free nitrogen. A mixture containing excess oxygen has a negative oxygen balance.

Parallel circuit.—A circuit in which two wires, called bus wires, extend from the lead wire. One leg wire from each cap in the circuit is hooked to each of the bus wires.

Parallel hole cut.—A group of parallel holes, some of which are loaded with explosives, used to establish a free face in tunnel or heading blasting. One or more of the unloaded holes may be larger than the blastholes. Also called Coromant, Cornish, burn, shatter, or Michigan cut.

Parallel series circuit.—Similar to a parallel circuit, but involving two or more series of electric blasting caps. One end of each series of caps is connected to each of the bus wires. Sometimes called series-in-parallel circuit.

Particle velocity.—A measure of ground vibration. Describes the velocity at which a particle of ground vibrates when excited by a seismic wave.

Pattern.—A plan of holes laid out on a face or bench which are to be drilled for blasting. Burden and spacing dimensions are usually expressed in feet.

Pellet powder.—Black powder pressed into 2-inch-long, 1-1/4- to 2-inch diameter cylindrical pellets.

Pentaerythritoltetranitrate (PETN).—A military explosive compound used as the core load of detonating cord and the base charge of blasting caps.

Pentolite.—A mixture of PETN and TNT which, when cast, is used as a cast primer.

Permissible.—A machine, material, apparatus, or device that has been investigated, tested, and approved by the Bureau of Mines or MSHA, and is maintained in permissible condition (MSHA).

Permissible blasting.—Blasting according to MSHA regulations for underground coal mines or other gassy underground mines.

Permissible explosives.—Explosives that have been approved by MSHA for use in underground coal mines or other gassy mines.

PETN.—*See* pentaerythritoltetranitrate.

Placards.—Signs placed on vehicles transporting hazardous materials, including explosives, indicating the nature of the cargo.

Plaster shot.—*See* mud cap.

Pneumatic loader.—One of a variety of machines, powered by compressed air, used to load bulk blasting agents or cartridged water gels.

Powder.—Any solid explosive.

Powder chest.—A substantial, nonconductive portable container equipped with a lid and used at blasting sites for temporary storage of explosives.

Powder factor.—A ratio between the amount of powder loaded and the amount of rock broken, usually expressed as pounds per ton or pounds per cubic yard. In some cases, the reciprocals of these terms are used.

Preblast survey.—A documentation of the existing condition of a structure. The survey is used to determine whether subsequent blasting causes damage to the structure.

Premature.—A charge that detonates before it is intended. Prematures can be hazardous.

Preshearing.—*See* presplitting.

Presplitting.—A form of controlled blasting in which decoupled charges are fired in closely spaced holes at the perimeter of the excavation. A presplit blast is fired before the main blast. Also called preshearing.

Pressure vessel.—A system for loading AN-FO into small-diameter blastholes. The AN-FO is contained in a sealed vessel, to which air pressure is applied, forcing the ANFO through a semiconductive hose and into the blasthole. Also known as pressure pot.

Prill.—In blasting, a small porous sphere of ammonium nitrate capable of absorbing more than 6 percent by weight of fuel oil. Blasting prills have a bulk density of 0.80 to 0.85 g/cm^3.

Primary blast.—The main blast executed to sustain production.

Primary explosive.—An explosive or explosive mixture, sensitive to spark, flame, impact or friction, used in a detonator to initiate the explosion.

Primer.—A unit, package, or cartridge of cap-sensitive explosive used to initiate other explosives or blasting agents and which contains a detonator (MSHA).

Propagation.—The detonation of explosive charges by an impulse from a nearby explosive charge.

Propagation blasting.—The use of closely spaced, sensitive charges. The shock from the first charge propagates through the ground, setting off the adjacent charge, and so on. Only one detonator is required. Primarily used for ditching in damp ground.

Propellant explosive.—An explosive that normally deflagrates and is used for propulsion.

Pull.—The quantity of rock or length of advance excavated by a blast round.

Radiofrequency energy.—Electrical energy traveling through the air as radio or electromagnetic waves. Under ideal conditions, this energy can fire an electric blasting cap. IME Pamphlet No. 20 recommends safe distances from transmitters to electric blasting caps.

Radiofrequency transmitter.—An electric device, such as a stationary or mobile radio transmitting station, which transmits a radiofrequency wave.

RDX.—Cyclotrimethylenetrinitramine, an explosive substance used in the manufacture of compositions B, C-3, and C-4. Composition B is useful as a cast primer.

Relievers.—In a heading round, holes adjacent to the cut holes, used to expand the opening made by the cut holes.

Rib holes.—The holes at the sides of a tunnel or drift round, which determine the width of the opening.

Riprap.—Coarse rocks used for river bank or dam stabilization to reduce erosion by water flow.

Rotational firing.—A delay blasting system in which each charger successively displaces its burden into a void created by an explosive detonated on an earlier delay period.

Round.—A group or set of blastholes required to produce a unit of advance in underground headings or tunnels.

Safety fuse.—A core of potassium nitrate black powder, enclosed in a covering of textile and waterproofing, which is used to initiate a blasting cap or a black powder charge. Safety fuse burns at a continuous, uniform rate.

Scaled distance.—A ratio used to predict ground vibrations. As commonly used in blasting, scaled distance equals the distance from the blast to the point of concern, in feet, divided by the square root of the charge weight of explosive per delay, in pounds. Normally, when using the equation, the delay period must be at least 9 ms.

Secondary blasting.—Using explosives to break boulders or high bottom resulting from the primary blast.

Seismograph.—An instrument that measures and may supply a permanent record of earthborne vibrations induced by earthquakes or blasting.

Semiconductive hose.—A hose, used for pneumatic loading of AN-FO, which has a minimum electrical resistance of 1,000 ohms/ft and 10,000 ohms total resistance and a maximum total resistance of 2,000,000 ohms.

Sensitiveness.—A measure of an explosive's ability to propagate a detonation.

Sensitivity.—A measure of an explosive's susceptibility to detonation upon receiving an external impulse such as impact, shock, flame, or friction.

Sensitizer.—An ingredient used in explosive compounds to promote greater ease in initiation or propagation of the detonation reaction.

Sequential blasting machine.—A series of condensor discharge blasting machines in a single unit which can be activated at various accurately timed intervals following the application of electrical current.

Series circuit.—A circuit of electric blasting caps in which each leg wire of a cap is connected to a leg wire from the adjacent caps so that the electrical current follows a single path through the entire circuit.

Series-in-parallel circuit.—*See* parallel series circuit.

Shatter cut.—*See* parallel hole cut.

Shelf life.—The length of time for which an explosive can be stored without losing is efficient performance characteristics.

Shock energy.—The shattering force of an explosive causes by the detonation wave.

Shock tube system.—A system for initiating caps in which the energy is transmitted to the cap by means of a shock wave inside a hollow plastic tube.

Shock wave.—A pressure pulse that propagates at supersonic velocity.

Shot.—*See* blast.

Shot firer.—Also referred to as the shooter. The person who actually fires a blast. A powderman, on the other hand, may charge or load blastholes with explosives but may not fire the blast.

Shunt.—A piece of metal or metal foil which short circuits the ends of cap leg wires to prevent stray currents from causing accidental detonation of the cap.

Silver chloride cell.—A low-current cell used in a blasting galvanometer and other devices used to measure continuity in electric blasting caps and circuits.

Slurry.—An aqueous solution of ammonium nitrate, sensitized with a fuel, thickened, and crosslinked to provide a gelatinous consistency. Sometimes called a water gel. DOT may classify a slurry as a Class A explosive, a Class B explosive or a blasting agent. An explosive or blasting agent containing substantial portions of water (MSHA). *See* emulsion; water gel.

Smooth blasting.—A method of controlled blasting, used underground, in which a series of closely spaced holes is drilled at the perimeter loaded with decoupled charges, and fired on the highest delay period of the blast round.

Snake hole.—A borehole drilled slightly downward from a horizontal into the floor of a quarry face. Also, a hole drilled under a boulder.

Sodium nitrate.—An oxidizer used in dynamites and sometimes in blasting agents.

Spacing.—The distance between boreholes or charges in a row, measured perpendicular to the burden and parallel to the free face of expected rock movement.

Specific gravity.—The ratio of the weight of a given volume of any substance to the weight of an equal volume of water.

Spitter cord.—*See* Ignitacord.

Springing.—*See* chambering.

Square pattern.—A pattern of blastholes in which the holes in succeeding rows are drilled directly behind the holes in the front row. In a truly square pattern the burden and spacing are equal.

Squib.—A firing device that burns with a flash. Used to ignite black powder or pellet powder.

Stability.—The ability of an explosive material to maintain its physical and chemical properties over a period of time in storage.

Staggered pattern.—A pattern of blastholes in which holes in each row are drilled between the holes in the preceding row.

Static electricity.—Electrical energy stored on a person or object in a manner similar to that of a capacitor. Static electricity may be discharged into electrical initiators, thereby detonating them.

Steady state velocity.—The characteristic velocity at which a specific explosive, under specific conditions, in a given charge diameter, will detonate.

Stemming.—The inert material, such as drill cuttings, used in the collar portion (or elsewhere) of a blasthole to confine the gaseous products of detonation. Also, the length of blasthole left uncharged.

Stick count.—*See* cartridge count.

Stray current.—Current flowing outside its normal conductor. A result of defective insulation, it may come from electrical equipment, electrified fences, electric railways, or similar items. Flow is facilitated by conductive paths such as pipelines and wet ground or other wet materials. Galvanic action of two dissimilar metals, in contact or connected by a conductor, may cause stray current.

Strength.—A property of an explosive described in various terms such as cartridge or weight strength, seismic strength, shock or bubble energy, crater strength, or ballistic mortar strength. Not a well-defined property. Used to express an explosive's capacity to do work.

String loading.—The procedure of loading cartridges end to end in a borehole without deforming them. Used mainly in controlled blasting and permissible blasting.

Subdrill.—To drill blastholes beyond the planned grade lines or below floor level to insure breakage to the planned grade or floor level.

Subsonic.—Slower than the speed of sound.

Supersonic.—Faster than the speed of sound.

Swell factor.—The ratio of the volume of a material in it solid state to that when broken. May also be expressed as the reciprocal of this number.

Sympathetic propagation (sympathetic detonation).—Detonation of an explosive material by means of an impulse from another detonation through air, earth, or water.

Tamping.—The process of compressing the stemming or explosive in a blasthole. Sometimes used synonymously with stemming.

Tamping bag.—A cylindrical bag containing stemming material, used to confine explosive charges in boreholes.

Tamping pole.—*See* loading pole.

Test blasting cap No. 8.—A detonator containing 0.40 to 0.45 g of PETN base charge at a specific gravity of 1.4 g/cm^3, and primed with standard weights of primer, depending on the manufacturer.

Toe.—The burden or distance between the bottom of a borehole and the vertical free face of a bench in an excavation. Also the rock left unbroken at the foot of a quarry blast.

Transient velocity.—A velocity, different from the steady state velocity, which a primer imparts to a column of powder. The powder column quickly attains steady state velocity.

Trinitrotoluene (TNT).—A military explosive compound used industrially as a sensitizer for slurries and as an ingredient in pentolite and composition B. Once used as a free-running pelletized powder.

Trunkline.—A detonating cord line used to connect the downlines of other detonating cord lines in a blast pattern. Usually runs along each row of blastholes.

Tunnel.—A horizontal underground passage.

Two-component explosive.—*See* binary explosive.

Unconfined detonation velocity.—The detonation velocity of an explosive material not confined by a borehole or other confining medium.

V-cut.—A cut employing several pairs of angled holes, meeting at the bottoms, used to create free faces for the rest of the blast round.

Velocity.—The rate at which the detonation wave travels through an explosive. May be measured confined or unconfined. Manufacturer's data are sometimes measured with explosives confined in a steel pipe.

Venturi loader.—*See* jet loader.

Volume strength.—*See* cartridge strength or bulk strength.

Water gel.—An aqueous solution of ammonium nitrate, sensitized with a fuel, thickened, and crosslinked to provide a gelatinous consistency. Also called a slurry. May be an explosive or a blasting agent.

Water resistance.—A qualitative measure of the ability of an explosive or blasting agent to withstand exposure to water without becoming deteriorated or desensitized.

Water stemming bags.—Plastic bags containing a self-sealing device, which are filled with water. Classified as a permissible stemming device by MSHA.

Weight strength.—A rating that compares the strength of a given weight of explosive with an equivalent weight of straight nitroglycerin dynamite, or other explosive standard, expressed as a percentage.

Chapter 19

WASTE IN RIPRAP PRODUCTION

Introduction

Most embankment dams constructed by the Bureau of Reclamation contain at least one zone that requires the production of rock. The rock is used as riprap for protection against erosion, or as rockfill and filter zones that strengthen or drain the embankment. Production of this material generally requires drilling, blasting, and processing to obtain the desired sizes. This chapter is a guide to estimate the amount of waste that can be expected from riprap production.

In an early court case against a governmental agency involved in construction, a waste quantity of 15 percent was determined to be reasonable when quarrying rock for riprap. Other court claims for different sites followed, and awards were made in the Contractor's favor based on the original case. Recent data from quarries and discussions with Contractors and Reclamation personnel suggest that this quantity is much too low (see table 19-1).

Contributors to Waste in Raprap Production

Numerous factors in the parent rock contribute to waste in quarrying operations. They include:

1. Weathering;
2. Fracturing (joints, shears and faults);
3. Bedding, schistosity and foliation;
4. Recementing of planar features;
5. Size and gradation requirements;
6. Construction inspection;
7. Drilling and blasting; and
8. Processing, hauling and placement.

The first four factors are related to the geology in the quarry and probably are the most important factors that govern

Table 19-1. – Rock types vs usable quantity of riprap.

Rock Type	Estimated percent waste to produce suitable riprap	Remarks
IGNEOUS		
intrusive	25 to 75% Average 50%±	
extrusive	40 to 85% Average 60%±	
METAMORPHIC		
Gneiss	40 to 75% Average 55%±	Based on limited data.
Schist	50 to 75% Average 65%±	Based on limited data. Very little ripwap would be salvaged in weathered zone.
SEDIMENTARY		
Limestone/ Dolomite	55 to 85% Average 65%±	Based on several good quarry sites.
Sandstone	Average 60%±	Based on limited data.

what sizes can be produced. It is not uncommon for weathering to extend to depths of 20 to 60 feet (6 to 18 meters) below the original ground surface. This deterioration breaks down the rock and weakens existing planar features such as bedding, schistosity and jointing. In some rocks such as limestone and dolomite, secondary deposits of calcium carbonate cement existing joints. When first viewed, this cementation appears to be sound, but processing the rock easily can refracture these planes. Existing quarries, or quarries that have been in operation for many years, probably will produce material with less waste because excavations are partly or completely through the zone of weathering. New quarries, or quarries where rock production has been limited, must contend with the weathered zone and will likely produce less desirable product.

Gradation Requirements

Gradation requirements and inspection control are governed by the agency issuing the construction specifications. Adjustments in gradation and/or inspection requirements can alter drastically the waste quantities produced. Except in isolated cases, it becomes more difficult to produce riprap when rock sizes are increased and gradations are tightly controlled.

Production Methods

Production methods which include drilling, blasting, processing and hauling also play an important role in what sizes can be obtained. Generally, product rock that is well graded with large maximum size can be produced more readily when using larger diameter shot holes at more distant spacings. Closer spaced and smaller shot holes will tend to maximize fragmentation. Blasting agents, delays and methods of loading vary considerably and have a great effect on how the rock fractures. The most efficient and economical drilling and blasting methods must be determined by test blasting and performing gradations on the blasted product. Test shots should be modified to achieve the desired graded product. Production should not start until it is proven that the required product can be produced with a minimum quantity of waste.

Many rock types, especially those that are banded (bedding or schistosity) or contain healed joints, can break down badly during processing. Some limestones are especially susceptible to breakdown during processing or when the rock is dropped during blasting and processing operations. Rock from most quarries will fracture badly when dropped more than 50 feet.

Collected Data Presentation

Information from numerous quarries, including rock excavations have been obtained from various sources throughout the western United States. These data are presented on tables 19-2 through 19-4. Much of the information is based on estimates as little documentation is available. Difficulties in determining rock weights and volumes contribute to the problem. Because each job has different requirements, quarries must tailor their blasting techniques to achieve the limits established. Quarries that normally produce aggregates for concrete, road metals, base course, etc., usually have a very difficult time in producing a reasonably well graded riprap.

This is because their normal operation already has shattered the face at least 100 feet behind it. To obtain a good riprap product a working face or ledge should have been reserved for the purpose of riprap production.

Based on data presented in tables 19-2 through 19-4 and giving consideration to the judgments arrived at through discussions with various government and private personnel, the quantity of quarry waste shown in table 19-1 can be anticipated.

Additional items that should be considered when using the table include:

1. The waste includes undersize and excessive intermediate sizes. Oversize riprap is reprocessed to the proper size.

2. The rock produced is reasonably well graded from 6± to 36± inches and the inspection control is very strict. Much less waste will be incurred if smaller rock sizes are required or if the deposit is shot for rockfill or the specific rock product.

3. Drilling, blasting, processing, hauling and placing are accomplished by a typical contractor.

4. Rock quarried is in the best material available and is not severely fractured or weathered. Except for gneiss and schist, rock units are massive or thickly bedded.

5. Generally riprap production is limited to new quarries, or unshot ledges or benches.

DATA ON METAMORPHIC ROCK AND RIPRAP QUARRIES

COMPILED BY GLENN J. TAUCHER 1986-1987 SHEET 1 OF 1

PROJECT AND QUARRY	YEAR	ROCK TYPE 1/AND CHARACTERISTICS (JOINTING, BEDDING AND WEATHERING)	INVESTIGATIONS CONDUCTED PRIOR TO QUARRYING (DRILLING-TEST BLASTING) INCLUDE COST	LAB TEST DATA	NEW OR EXISTING QUARRY	DRILLING DATA (ANGLE, SIZE, DEPTH AND SPACING OF SHOTS OR COYOTE HOLES	BLASTING DATA (EXPLOSIVES, POWDER FACTORS, DELAYS ETC.)	EQUIPMENT USED	BREAKDOWN DURING PROCESSING 2/	PERCENT WASTE (MEASURED OR ESTIMATED)	WASTE INCLUDED "A" OR "B" 3/	WAS WASTE USED FOR OTHER PURPOSES (YES OR NO)? WHAT?	CONTRACTORS ESTIMATE $/TON OR $/YARD AMOUNT PRODUCED HAUL DISTANCE	CONTRACTOR CLA (YES OR NO) ? AMOUNT	ROCK SIZE REQUIREMENT	DATA FROM	SERVICE RECORD	REMARKS
DEERFIELD DAM MODIFICATION SPILLWAY EXCAVATION SOUTH DAKOTA	1983 AND 1984	PRECAMBRIAN BIOTITE SCHIST FD-9 FRACTURING & W-7 TO -9 WEATHERING 0-5'; FD-7 TO -8 FRACTURING & W-5 TO -6 WEATHERING 5-15'; FD-5 TO -6 FRACTURING & W-4 WEATHERING 15-40'; FD-3 TO -4 FRACTURING & W-2 TO -3 WEATHERING BELOW 40'. SCHISTOSITY DIPS 45-60°	3 NX-SIZE CORE HOLES RANGING FROM 89.5 TO 122.2' IN DEPTH, SEISMIC SURVEY AND GEOLOGIC MAPPING. COST NOT DETERMINED.	SCHIST SAMPLES SENT TO E & R CENTER FOR TESTING. DATA NOT AVAILABLE.	SPILLWAY EXCAVATION UP TO 130' DEEP.	3-4" DIAMETER VERTICAL HOLES ON 6X8, 7X8 10X10 FT. PATTERNS. HOLES RANGED FROM 20-30' DEEP.	USED AN-FO WITH DELAYS. V-ECHELON BLAST ROUNDS GENERALLY USED. ABOUT 0.6 LBS./YD. POWDER FACTOR	DOZER, AIR TRACK DRILL, COMPRESSOR, FRONT END LOADERS, ROCK RAKE, STATIONARY GRIZZLY AND HAUL TRUCKS.	MODERATE TO HIGH BREAKDOWN IN HAULING AND COMPACTING ROCKFILL. LOW TO MODERATE BREAKDOWN WHEN PROCESSING RIPRAP.	ESTIMATED 95% USED FOR ROCKFILL OR RIPRAP. OF THIS AMOUNT ONLY ABOUT 4% WAS USED FOR RIPRAP. IF PROCESSING ONLY FOR RIPRAP AND USING SAME BLASTING TECHNIQUES, IT IS ESTIMATED THAT WASTE WOULD BE 100% FROM 0-15', 95% FROM 15-30', AND 65% FROM BELOW 30'. (FOOTAGE IS FOR DEPTH OF CUT).	SEE COLUMN AT LEFT.	YES, ROCKFILL.	TOTAL EXCAVATION WAS ABOUT 316,00 YDS³ RIPRAP INCLUDED 12,700 YDS. HAUL WAS UNDER 1/2 MILE. COST OF RIPRAP PRODUCTION IMPOSSIBLE TO SEPARATE.	NO CLAIM AS OF DECEMBER, 1984.	FOR RIPRAP 0-10% MINUS 100 LBS. 60-70 % 100 TO 2200 LBS. 30-40% 2200 TO 4500 LBS. MAXIMUM SIZE 4500 LBS.	K. BARNES CONSTRUCTION ENGINEER; & G. TAUCHER (REGIONAL GEOLOGIST)	SIMILAR SCHIST RIPRAP HAS FACED DEERFIELD DAM FOR OVER 40 YEARS. ONLY MINOR BREAK-DOWN HAS OCCUR-RED.	ROCK PRODUCED FROM SPILLWAY EXCAVATION WAS USED IN ROCKFILL FOR DEERFIELD DAM. LARGER SIZES WERE PROCESSED FOR RIPRAP. SCHIST REMOVED FROM SPILLWAY EXCAVATION AND COMPACTED IN 2 FOOT ROCKFILL LIFTS IN DAM, BULKED ABOUT 10 PERCENT.
PACTOLA DAM SPILLWAY EXCAVATION SOUTH DAKOTA	1955 ?	PRECAMBRIAN SCHIST, AMPHIBOLITE AND SLATE.	DRILLING AND MAPPING. COST NOT DETERMINED.	NO RECORD OF TESTING.	SPILLWAY EXCAVATION	NOT AVAILABLE	UNKNOWN	UNKNOWN	PROBABLY MODERATE	MEASURED 54%	UNKNOWN	YES, ZONE 2 FILL WHICH CONSISTED OF 1-8" ROCK	NOT AVAILABLE	UNKNOWN	ZONE 2 - FREE DRAINING AND PREDOMINATELY PLUS 6" AND UP TO 1 YD 3 SEE REMARKS COLUMN.	FINAL CONSTRUCTION REPORT ON PACTOLA DAM	RIPRAP ON FACE OF PACTOLA DAM IS EXCELLENT CONDITION AFTER 25± YEARS OF OPERATION	OF THE 54% WASTE FOR ZONE 3, 7% ENDED UP BEING UNUSABLE AND 47% WAS USED IN ZONE 2. LARGER ROCK RAKED TO OUTSIDE OF DAM FOR RIPRAP PROTECTION. MOST OF LARGER ROCK ENDED UP BEING FRAGMENTS OF AMPHIBOLITE. SLATE AND SCHIST FRAGMENTS BROKE SMALLER AND TENDED TO BE WORKED TOWARDS THE INSIDE PORTION OF ZONE 3. WHEN EXCAVATIONS WERE MADE INTO THE ZONE 3 IN 1985 AND 86, PARTICLE SIZES ENCOUNTERED WERE SMALLER THAN ANTICIPATED. ROCK PARTICLES RANGED FROM SILT TO 36 INCH SIZES. (AVERAGE ESTIMATED AT 50% PASSING 3-IN. SCREEN).
PACTOLA DAM QUARRY IN RIGHT ABUTMENT SOUTH DAKOTA	1955 ?	PRECAMBRIAN AMPHIBOLITE WITH MINOR AMOUNTS OF SCHIST AND SLATE	DRILLING AND MAPPING. COST NOT DETERMINED	NO RECORD OF TESTING	NEW	UNKNOWN EXCEPT THAT AT LEAST PART WAS SHOT USING A COYOTE HOLE	UNKNOWN	UNKNOWN	PROBABLY LOW TO MODERATE	MEASURED 23%	UNKNOWN	YES, ZONE 2 FILL WHICH CONSISTED OF 1-8" ROCK	NOT AVAILABLE	UNKNOWN	ZONE 2 - FREE DRAINING AND PREDOMINATELY PLUS 6" AND UP TO 1 YD 3	FINAL CONSTRUCTION REPORT ON PACTOLA DAM	RIPRAP ON FACE OF PACTOLA DAM IN EXCELLENT CONDITION AFTER 25± YEARS OF OPERATION	OF THE 23% WASTE FOR ZONE 3, 1% ENDED UP BEING UNUSABLE AND 22 % WAS USED IN ZONE 2. LARGER ROCK RAKED TO OUTSIDE OF DAM FOR RIPRAP PROTECTION. REQUIREMENTS FOR ROCK NOT AS STRICT AS FOR TYPICAL RIPRAP. SEE REMARKS ABOVE (PACTOLA SPILLWAY EXCAVATION).
COLORADO RIVER FRONT WORK AND LEVEE SYSTEM (CRFWLS) SECTION 7 QUARRY CALIFORNIA		PRECAMBRIAN BIOTITE GNEISS	4 CORE HOLES AND TEST BLAST	UNKNOWN	NEW	3" DIAMETER VERTICAL HOLES ON 10' CENTERS. HOLES DRILLED TO 40'	1⅛ X 8" CARTRIDGE HERCULES UNIGEL AND NITRO CARBO NITRATE APPROXIMATELY 0.5 LBS / YD POWDER FACTOR	GRIZZLY, DOZER, FRONT END LOADERS, DRILL, AND HAUL TRUCKS.	PROBABLY LOW	ESTIMATED 25%	UNKNOWN	YES, ROAD SUBBASE	$5.60-$6.80/TON HAUL DISTANCE UNKNOWN	NO	6" TO 1/2YD³	D. BRANSTETTER (REGIONAL GEOLOGIST) R. MOYES (FIELD ENGINEER) & INSPECTOR REPORTS	UNKNOWN	SPECIFICATION REQUIREMENTS NOT AS STRICT AS THOSE USED FOR RIPRAP ON DAM EMBANKMENT
CRFWLS LAGUNA EAST QUARRY ARIZONA		PRECAMBRIAN BIOTITE GNEISS	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	PROBABLY LOW	ESTIMATED 35%	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	D. BRANSTETTER (REGIONAL GEOLOGIST) R. MOYES (FIELD ENGINEER) & INSPECTOR REPORTS	UNKNOWN	SPECIFICATION REQUIREMENTS NOT AS STRICT AS THOSE USED FOR RIPRAP ON DAM EMBANKMENTS
BAT COVE 1 & 2 CALIFORNIA		GNEISS	UNKNOWN	UNKNOWN	EXISTING	3" DIAMETER VERTICAL HOLES ON 10X10' PATTERN	TROVEX NITRO CARBO NITRATE AN-FO	GRIZZLY, DOZER, FRONT END LOADERS, DRILL & HAUL TRUCKS	PROBABLY LOW	ESTIMATED 35%	UNKNOWN	YES, SOME ROAD SUBBASE	NO.1 $5.70/TON NO. 2 $6.40/TON HAUL DISTANCE UNKNOWN	NO	6" TO 1/2YD³	D. BRANSTETTER (REGIONAL GEOLOGIST)	UNKNOWN	SPECIFICATION REQUIREMENTS NOT AS STRICT AS THOSE USED FOR RIPRAP ON DAM EMBANKMENTS
EHRENBERG, ARIZONA		GNEISS	UNKNOWN	UNKNOWN	EXISTING	3" DIAMETER VERTICAL HOLES. OTHER DATA NOT AVAILABLE	ATLAS KINSTICK CARTRIDGE, NITRO CARBO NITRATE	GRIZZLY, DOZER, FRONT END LOADERS, DRILL AND HAUL TRUCKS	PROBABLY LOW	ESTIMATED 35%	UNKNOWN	YES, SOME ROAD SUBBASE	$6.30/TON HAUL DISTANCE UNKNOWN	NO	6" TO 1/2YD³	D. BRAN-STETTER (REGIONAL GEOLOGIST)	UNKNOWN	SPECIFICATION REQUIREMENTS NOT AS STRICT AS THOSE USED FOR RIPRAP ON DAM EMBANKMENTS
AGNES WILSON CALIFORNIA		GNEISS	UNKNOWN	UNKNOWN	EXISTING	3" DIAMETER VERTICAL HOLES ON APPROXIMATE 12X12' PATTERN. HOLES 20-40' DEEP	TROVEX NITRO CARBO NITRATE	GRIZZLY, DOZER, FRONT END LOADERS, DRILL, AND HAUL TRUCKS	PROBABLY LOW	ESTIMATED 30%	UNKNOWN	YES, ROAD SUBBASE	UNKNOWN	NO	6" TO 1/2YD³	D. BRAN-STETTER (REGIONAL GEOLOGIST)	UNKNOWN	SPECIFICATION REQUIREMENTS NOT AS STRICT AS THOSE USED FOR RIPRAP ON DAM EMBANKMENTS
GRAND COULEE PROJECT, WASH. QUARRY 8 MILES WEST OF KETTLE FALLS, WASH.	1977	HORNBLEND SCHIST PLATY AND BREAKS IN RHOMBIC SHAPES WHEN QUARRIED	FIELD RECONNAISANCE	NONE	NEW	UNKNOWN	AN-FO OTHER DATA NOT AVAILABLE	UNKNOWN	MODERATE TO HIGH WHEN WORKED, HAULED, AND PLACED	ESTIMATED 60%	UNKNOWN	NO	COST UNKNOWN. HAULED ABOUT 1.5 MILES TO ST. PAUL MISSION SITE.	NO	ESTIMATED 6-24"	REX WYBORNEY (GEOLOGIST)	SCHIST IS PLATY AND TENDS TO FALL ON FLAT FACES. RIPRAP REMAINS IN GOOD SHAPE BUT RECEIVES ONLY MODERATE WAVE ACTION	THIS QUARRY WAS WORKED AGAIN IN 1982. WASTE ESTIMATED AT 50% DURING THE SECOND CONTRACT.
GRAND COULEE PROJECT, WASH. DAISY SHORELINE QUARRY 1 MILE NORTH OF DAISY, WASHINGTON	1984	QUARTZITE	FIELD RECONNAISANCE	NONE	NEW	UNKNOWN	UNKNOWN	UNKNOWN	LOW	ESTIMATED 20%	MOSTLY UNDERSIZE. VERY LITTLE OVERSIZE PRODUCED	NO	COST UNKNOWN. ROCK DEPOSIT ADJACENT TO SHORELINE SCHEDULED FOR PROTECTION.	NO	0-18"	REX WYBORNEY (GEOLOGIST)	APPEARS IN GOOD TO EXCELLENT CONDI-TION AFTER BEING IN PLACE FOR ONLY A SHORT PERIOD OF TIME	VERY LITTLE PROCESSING WAS DONE AS SPECIFICATIONS DID NOT HAVE STRICT REQUIREMENTS. MOST OF MATERIAL WAS PIT RUN.

1/ IF POSSIBLE, DESCRIBE JOINTING (FRACTURE DENSITY FD-1 THROUGH -9,* OPENNESS 0-0 THROUGH -5* AND FILLING); BEDDING/FOLIATION (TABLE 5-3*); AND WEATHERING (W-1 THROUGH -7*)

2/ ESTIMATE HIGH, MODERATE OR LOW PERCENTAGE OF ROCK BREAKDOWN DURING PROCESSING. IF ROCK BROKE DOWN, WAS IT DUE TO EQUIPMENT, SUCH AS A VIBRATING GRIZZLY?

3/ "A" (OVERSIZE, UNDERSIZE AND EXCESS OF INTERMEDIATE SIZES) OR "B" (UNDERSIZE AND EXCESS OF INTERMEDIATE SIZES OVERSIZE BROKEN DOWN BY SECONDARY BLASTING OR IMPACT HAMMERS)

* GEOLOGY FOR DESIGN AND SPECIFICATIONS OF THE ASSISTANT COMMISSIONER E & R CENTER DEC. 1981 (REVISED JUNE 1982)

Table 192. – Data on metamorphic rock and riprap quarries.

DATA ON IGNEOUS ROCK AND RIPRAP QUARRIES

COMPILED BY GLENN J. TAUCHER 1985-1987 SHEET 1 OF 2

PROJECT AND QUARRY	YEAR	ROCK TYPE 1/AND CHARACTERISTICS (JOINTING, BEDDING AND WEATHERING)	INVESTIGATIONS CONDUCTED PRIOR TO QUARRYING (DRILLING-TEST BLASTING) INCLUDE COST	LAB TEST DATA	NEW OR EXISTING QUARRY	DRILLING DATA (ANGLE, SIZE, DEPTH AND SPACING OF SHOTS OR COYOTE HOLES)	BLASTING DATA (EXPLOSIVES, POWDER FACTORS, DELAYS ETC.)	EQUIPMENT USED	BREAKDOWN DURING PROCESSING 2/	PERCENT WASTE (MEASURED OR ESTIMATED)	WASTE INCLUDED "A" OR "B" 3/	WAS WASTE USED FOR OTHER PURPOSES (YES OR NO)? WHAT?	CONTRACTORS ESTIMATE $/TON OR $/YARD AMOUNT PRODUCED HAUL DISTANCE	CONTRACTOR CLAIM (YES OR NO)? AMOUNT	ROCK SIZE REQUIREMENT	DATA FROM	SERVICE RECORD	REMARKS
TIBER DAM MODIFICATIONS QUARRY IN SWEET GRASS HILLS, MONTANA	1981	TERTIARY SYENITE LACCOLITH FD-7 FRACTURING & W-5 WEATHERING NEAR SURFACE, FD-3 & -4 FRACTURING & W-3 WEATHERING AT DEPTH. SOME CLAY SEAMS	NO RECORD OF DRILLING PRIOR TO 1955. SURFACE GEOLOGIC DATA GATHERED IN 1955 AND 1981. COST NOT DETERMINED.	LAB REPORT C-457C	EXISTING USED FOR RIPRAP ON TIBER DAM IN 1955.	USED BOTH DRILLING (BENCHING) AND COYOTE HOLES IN 1955. COYOTE HOLE WAS NOT TOO SUCESSFUL AS IT PRODUCED A LARGE AMOUNT OF OVERSIZE. OTHER DATA NOT AVAILABLE.	RECORDS NOT AVAILABLE FOR 1955. ONLY SECONDARY BLASTING DONE ON OVERSIZE BOULDERS IN 1981.	AIR TRACK DRILL, COMPRESSOR, HORAM, 2 FRONT END LOADERS, DOZER, STATIONARY GRIZZLY HAUL TRUCKS	LOW	ESTIMATED 45 % WASTE OVER GRIZZLY. THIS DID NOT INCLUDE OVERSIZE AS IT WAS BROKEN DOWN ESTIMATED 75 % WASTE IF UNDERSIZE AND OVERSIZE WAS REJECTED	SEE COLUMN AT LEFT	NO	5,000 TONS OF 10" RIPRAP AT $25/TON. 47,500 TONS OF 36"RIPRAP AT $23/TON. 12,400 TONS OF 35" RIPRAP AT $27.80/TON. ALL COSTS INCLUDE 45 MILE HAUL.	NO. HOWEVER, ADDITIONAL MATERIAL (12,400 TONS) WAS REQUIRED AT HIGHER PRICE.	6 TO 18 IN. AND 6 TO 36 IN. (0-15% MINUS 100#, 45-70% 100 TO 2250#, 30-40% PLUS 2250#.) MAXIMUM SIZE (4500 POUNDS).	K. BARNES (CONST ENGINEER) G. TAUCHER (REGIONAL GEOLOGIST)	RIPRAP ON FACE OF TIBER DAM IN EXCELLENT CONDITION AFTER 19 YEAR OPERATION PERIOD.	ROCK OBTAINED IN 1981 WAS UNUSED PORTION SHOT IN 1955 QUARRYING. NO MAJOR BLASTING IN 1981.
HELENA VALLEY DAM MODIFICATION QUARRY SOUTH OF HELENA, MONTANA	1980	TERTIARY RHYOLITE BRECCIA LAVA FLOW FD-3 TO -7 FRACTURING AND W-3 WEATHERING. NUMEROUS CLAY FILLED FRACTURES UP TO 1-FT. WIDE.	NO RECORD OF DRILLING PRIOR TO 1959. SURFACE GEOLOGIC DATA GATHERED IN 1979. COST LESS THAN $500.	NO RECORD OF TESTING.	EXISTING USED FOR RIPRAP ON HELENA VALLEY DAM IN 1959.	1955 RECORDS NOT AVAILABLE. 1980 HOLES WERE 2 1/2 IN. DIAMETER ON 6 X 6-FT. CENTERS AND 20 TO 30 FEET DEEP. ALL HOLES WERE VERTICAL.	1959 RECORDS NOT AVAILABLE. USED AN-FO WITH DELAYS. POWDER FACTOR NOT AVAILABLE.	HORAM, DOZER, CRANE WITH HEADACHE BALL, 2 FRONT END LOADERS, HAUL TRUCKS AND VIBRATING GRIZZLY	LOW	MEASURED 56 % WASTE ON UNDERSIZE ONLY. BREAKDOWN OF OVERSIZE DISCONTINUED BECAUSE OF EXPENSE. ESTIMATED 75 % WASTE WHEN ADDING UNDERSIZE AND OVERSIZE	SEE COLUMN AT LEFT	UNDERSIZE USED LATER BY COUNTY FOR ROAD SURFACING.	31,000 YDS³ OF 1 TO 18-IN. (SOME 6 TO 18-IN.)ROCK AT $17.97/YD . 800 YDS³ OF 6 TO 30-IN. RIPRAP AT $21.45/YD . ALL COSTS INCLUDE 10 MILE HAUL.	NO CLAIM ON 1959 CONTRACT. CONTRACTOR WAS AWARDED $55,000 FOR CLAIM ON 1980 CONTRACT.	WELL GRADED 1 TO 18 IN. (INCLUDED SOME 6 TO 18 IN.) AND 6 TO 30 IN. ROCK.	K. BARNES (CONST ENGINEER) C. VOLK (CONST REP.) G. TAUCHER (REGIONAL GEOLOGIST)	RIPRAP ON FACE OF HELENA VALLEY DAM IN GOOD TO EXCELLENT CONDITION AFTER 24 YEARS OF OPERATION. SOME ROUNDING OF EDGES HAS TAKEN PLACE	QUARRY PREVIOUSLY USED FOR RIPRAP AT HELENA VALLEY DAM IN 1959.CONTRACTOR CLAIMED THAT CLAY SEAMS CAUSED MUCH OF HIS PROBLEM IN DRILLING AND BLASTING. THESE WERE READILY VISIBLE IN QUARRY WALL LEFT AFTER 1959 OPERATION.
BANK PROTECTION UPSTREAM FROM CANYON FERRY DAM, MONTANA QUARRY IN UPSTREAM LEFT ABUTMENT NEAR DAM.	1965	TERTIARY GRANO-DIORITE INTRUSION FD-3 TO -7 FRACTURING AND W-3 WEATHERING	NONE	NONE	NEW	3-IN. (DIAMETER VERTICAL HOLES ON 6 X 6- FT. CENTERS. HOLES 20 TO 40-FT. DEEP	AN-FO, NO OTHER DATA AVAILABLE	AIR TRACK DRILL, COMPRESSOR, FRONT END LOADER, DRAGLINE AND HAUL TRUCKS.	LOW	ESTIMATED 65 %	B	NO	NOT AVAILABLE	NO	6 TO 36 IN. FAIRLY WELL GRADED.	C. VOLK (CONST. REP.)	RIPRAP IN PLACE ABOUT 19 YEARS. NO VISIBLE BREAKDOWN.	
COLORADO IVER FRONT ORK AND EVEE SYSTEM CRFWLS) AVIS DAM UARRY, VADA		TERTIARY GRANITE	UNKNOWN	UNKNOWN	EXISTING	3-IN. DIAMETER VERTICAL HOLES ON 9-FT. CENTERS. HOLES DRILLED TO DEPTHS OF 20, 24, AND 25 FEET.	ATLAS KINESTICK, 60 % AUSTIN APOGEL AND NITRO CARBO NITRATE. APPROXIMATELY 1.25 LBS/YDS³ POWDER FACTOR	GRIZZLY DOZER, FRONT END LOADERS HAUL TRUCKS AND DRILL	PROBABLY LOW	ESTIMATED 30 %	UNKNOWN	NO	$7.20 TO 8.40/TON. HAUL DISTANCE NOT KNOWN	NO	6-IN. TO 1/2 YD.³.	D. BRAN-STETTER (REGIONAL GEOLOGIST) R. MOYERS (FIELD ENGR.) AND INSPT. REPORTS	UNKNOWN	SPECIFICATION REQUIREMENTS NOT AS STRICT AS THOSE USED FOR RIPRAP ON DAM EMBANKMENTS.
FWLS GO WASH, ZONA		TERTIARY WELDED RHYOLITIC TUFF	UNKNOWN	UNKNOWN	UNKNOWN	3-IN. DIAMETER VERTICAL HOLES ON 9 TO 10-FT. CENTERS. HOLES DRILLED TO AN AVERAGE DEPTH OF 21- FT.	1 1/4 X 8 -IN. CARTRIDGE HERCULES UNIGEL AND NITRO CARBO NITRATE. APPROXIMATELY 0.75 LBS/YD³ POWDER FACTOR	GRIZZLY DOZER, FRONT END LOADERS, DRILL AND HAUL TRUCKS	UNKNOWN	ESTIMATED 35 %	UNKNOWN	UNKNOWN	$7.70 TO $8.80/TON. HAUL DISTANCE NOT KNOWN.	UNKNOWN	6-IN. TO 1/2/YD.³.	D. BRAN-STETTER (REGIONAL GEOLOGIST), R. MOYERS (FIELD ENGR.) AND INSPT. REPORTS	UNKNOWN	SPECIFICATION REQUIREMENTS NOT AS STRICT AS THOSE USED FOR RIPRAP ON DAM EMBANKMENTS.
FWLS RAP QUARRY, LIFORNIA		DIORITE	UNKNOWN	UNKNOWN	EXISTING	3- IN. DIAMETER VERTICAL HOLES ON 12 X 12- FT. PATTERN. HOLES DRILLEU TO A DEPTH OF 23- FT.	AN-FO 0.81 LBS/YD³ POWDER FACTOR	GRIZZLY DOZER, FRONT END LOADERS, DRILL AND HAUL TRUCKS.	PROBABLY LOW	ESTIMATED 25 %	UNKNOWN	UNKNOWN	$5.80 TO $7.80/TON. HAUL DISTANCE NOT KNOWN.	NO	6-IN. TO 1/2 YD.³.	D. BRAN-STETTER (REGIONAL GEOLOGIST) R. MOYERS (FIELD ENGR.) AND INSPT. REPORTS	UNKNOWN	SPECIFICATION REQUIREMENTS NOT AS STRICT AS THOSE USED FOR RIPRAP ON DAM EMBANKMENTS.
FWLS ART MINE, IZONA		TERTIARY ANDESITE	UNKNOWN	UNKNOWN	UNKNOWN	3- IN. DIAMETER VERTICAL HOLES ON 7 X 9 AND 14 X 14 -FT. PATTERNS. HOLES DRILLED TO 10, 15 AND 35 -FT. DEPTHS.	1 3/4 X 8 - IN. ATLAS CARTRIDGE, 75 % POWER PRIMER, AN-FO AND NITRO CARBO NITRATE. POWDER FACTOR NOT AVAILABLE.	GRIZZLY DOZER FRONT END LOADERS, DRILL AND HAUL TRUCKS.	PROBABLY LOW	ESTIMATED 30 %	UNKNOWN	YES SOME ROAD BASE	$6.40 TO $7.30/TON. HAUL DISTANCE NOT KNOWN.	NO	6-IN. TO 1/3 YD.³.	D. BRAN-STETTER (REGIONAL GEOLOGIST), R. MOYERS (FIELD ENGR.) AND INSPT. REPORTS	UNKNOWN	SPECIFICATION REQUIREMENTS NOT AS STRICT AS THOSE USED FOR RIPRAP ON DAM EMBANKMENTS.
L ELBERT REBAY RRY PEAK ARRY, LORADO ECIFICATION -7144	1975 TO 1977	QUARTZ MONZONITE RANGED FROM MASSIVE TO HIGHLY FRACTURED WITH CLAY SEAMS.	THREE NX-SIZE CORE HOLES AND BLAST TEST. COST NOT DETERMINED	SPECIFIC GRAVITY 2.64	NEW WORKED 1st BY SUB-CONTRACTOR AND 2nd BY PRIME CONTRACTOR	GENERALLY 3- IN. DIAMETER VERTICAL HOLES ON 6 X 6 OR 8 X 8 -FT. CENTERS. HOLES GENERALLY DRILLED TO 10 OR 12 -FT. DEPTHS.	EXPLOSIVE DATA NOT AVAILABLE 0.8 TO 1.0 LBS/YD³ POWDER FACTOR	GRIZZLY DOZER, FRONT END LOADERS, DRILL, CRANE WITH HEADACHE BALL AND HAUL TRUCKS	LOW	WASTE UNDER SUBCONTRACTOR WAS MEASURED AT 40 %. (HE CLAIMED 60 %) WASTE UNDER PRIME CONTRACTOR WAS 27 %	A	YES MINOR AMOUNT USED FOR ROAD SURFACING	SUBCONTRACTOR CLAIMED THAT COST EXCEEDED $8/TON TO PRODUCE RIPRAP AT QUARRY. NO OTHER DATA AVAILABLE.	YES: WITH SUBCONTRACTOR. HE WAS AWARDED $100,000.	6-IN. TO 24-IN. FAIRLY WELL GRADED.	G. TUTTLE (REGIONAL GEOLOGIST) B. McCORMICK (ENGINEER) AND CONST. CLAIM	UNKNOWN	SUBCONTRACTOR CLAIMED DEPOSIT BADLY FRACTURED, DECOMPOSED IN AREAS, CONTAINED NUMEROUS CLAY SEAMS AND SIMILAR TO BOULDER BEDS.
ER WALL AT DAMELLE, AH		ANDESITE	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	PROBABLY LOW	ESTIMATED 50 %	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	ARMOR ROCK	F. THOMPSON (REGIONAL GEOLOGIST)	UNKNOWN	
ON DAM N JUAN- AMA, MEXICO		BASALT	NONE	UNKNOWN	NEW	UNKNOWN	UNKNOWN	UNKNOWN	PROBABLY LOW	ESTIMATED 30 TO 40 %	UNKNOWN	NO	UNKNOWN	NO	1/2 FT.³ TO 1 YD.³	JOE JACKSON (REGIONAL GEOLOGIST)	UNKNOWN	

/ IF POSSIBLE DESCRIBE JOINTING (FRACTURE DENSITY FD-1 THROUGH -9* OPENNESS O-1 THROUGH -5* AND FILLING), BEDDING/FOLIATION (TABLE 5-3*), AND WEATHERING (W-1 THROUGH -7*)

/ ESTIMATE HIGH, MODERATE OR LOW PERCENTAGE OF ROCK BREAKDOWN DURING PROCESSING. IF ROCK BROKE DOWN, WAS IT DUE TO EQUIPMENT, SUCH AS A VIBRATING GRIZZLY?

/ "A" (OVERSIZE, UNDERSIZE AND EXCESS OF INTERMEDIATE SIZES) OR "B" (UNDERSIZE AND EXCESS OF INTERMEDIATE SIZES OVERSIZE BROKEN DOWN BY SECONDARY BLASTING OR IMPACT HAMMERS)

GEOLOGY FOR DESIGN AND SPECIFICATIONS OF THE ASSISTANT COMMISSIONER E & R CENTER DEC. 1981 (REVISED JUNE 1982)

Table 19-3. – Data on igneous rock and riprap quarries.

DATA ON IGNEOUS ROCK AND RIPRAP QUARRIES

COMPILED BY GLENN J. TAUCHER-1986-1987 SHEET 2 OF 2

Y	YEAR	ROCK TYPE 1/AND CHARACTERISTICS (JOINTING, BEDDING AND WEATHERING)	INVESTIGATIONS CONDUCTED PRIOR TO QUARRYING (DRILLING-TEST BLASTING) INCLUDE COST	LAB TEST DATA	NEW OR EXISTING QUARRY	DRILLING DATA (ANGLE, SIZE, DEPTH AND SPACING OF SHOTS OR COYOTE HOLES	BLASTING DATA (EXPLOSIVES, POWDER FACTORS, DELAYS ETC.)	EQUIPMENT USED	BREAKDOWN DURING PROCESSING 2/	PERCENT WASTE (MEASURED OR ESTIMATED)	WASTE INCLUDED "A" OR "B" 3/	WAS WASTE USED FOR OTHER PURPOSES (YES OR NO)? WHAT?	CONTRACTORS ESTIMATE $/TON OR $/YARD AMOUNT PRODUCED HAUL DISTANCE	CONTRACTOR CLAIM (YES OR NO)? AMOUNT	ROCK SIZE REQUIREMENT	DATA FROM	SERVICE RECORD	REMARKS
TION	1978 TO 1979	QUARTZ MONZONITE. RANGED FROM MASSIVE TO HIGHLY FRACTURED WITH CLAY SEAMS	SEE EXPLORATIONS LISTED UNDER QUARRY FOR MT. ELBERT FOREBAY	SPECIFIC GRAVITY 2.64	EXISTING PREVIOUSLY WORKED FOR RIPRAP ON MT. ELBERT FOREBAY (SEE ABOVE)	3" DIAMETER VERTICAL HOLES ON 9'X 9' PATTERNS. HOLES MOSTLY 20' DEEP	AN-FO AND 2X16" TOREX. 0.8 TO 1.2 LBS/YD^3 POWDER FACTOR	GRIZZLY, DOZER, FRONT END LOADERS, ROCK RAKE AND BUCKET, DRILL, HAUL TRUCKS, ETC.	LOW	MEASURED 22% (SOLID VOLUME V*, TONS PLACED)	UNDERSIZE	NO	30,000 TONS OF MOSTLY 36" MAXIMUM SIZED RIPRAP AT $13.00/TON (INCLUDES ABOUT 8 MILE HAUL)	NO	24" THICKNESS: 30-40% 625-1250 LBS; 60-70% 50-625 LBS;AND 0-10% MINUS 50 LBS. (MAX. SIZE 1250 LBS) 36" THICKNESS: 30-40% 2250-4500LBS; 60-70% 100-2250 LBS; AND 0-10% MINUS 100 LBS. (MAX. SIZE 4500 LBS)	B. McCORMICK (ENGINEER)	UNKNOWN	SPECIFICATION DC-7300 REQUIRED THAT ROCK (1) HAVE A SPECIFIC GRAVITY IN EXCESS OF 2.60 (SATURATED SURFACE - DRY); (2) HAVE LESS THAN 4% LOSS OF WEIGHT AFTER 5 CYCLES ON SOUNDNESS TEST (SODIUM-SULFATE METHOD); AND (3) HAVE LESS THAN 40% LOSS OF WEIGHT AFTER 500 REVOLUTIONS ON ABRASION TEST (USING LOS ANGELES MACHINE GRADING A).
LEE ASH D	1983 TO 1986	MEDIUM GRAINED GRANITE TO DIORITIC GRANITE INTERSPERSED WITH PEGMATITIC AND MAFIC DIKES. FINELY CRYSTALLINE JOINTS ON 1 TO 5 FT. CENTERS WITH AREAS OF INTENSE JOINTING AND SHEARING. WEATHERING GENERALLY RESTRICTED TO UPPER 20 FT. EXCEPT ALONG SHEAR ZONES WHERE IT EXTENDS CONSIDERABLY DEEPER.	FIELD RECONNAISSANCE AND DRILLED SEVERAL CORE HOLES. COST UNKNOWN.	SPECIFIC GRAVITY 2.65-2.70	NEW	3" DIAMETER VERTICAL WITH OCCASIONAL RANDOMLY SPACED ANGLE DRILL HOLES. MOSTLY DRILLED ON 9X10.5' PATTERN.	AN-FO 0.4 TO 0.5 LBS/YD^3 POWDER FACTOR	GRIZZLY, DOZER FRONT END LOADERS, AIR TRACK DRILL, HAUL TRUCKS, SHOVEL, BACKHOE AND OTHER EQUIPMENT.	LOW	MEASURED 56.5% WASTE.	A	3" PLUS MATERIAL USED FOR BEDDING BENEATH RIPRAP ALSO USED FOR ROAD CONSTRUCTION AND ENLARGEMENT OF WORK SITE.	2,800,000* TONS AT $5.70/TON (INCLUDES 3-6 MILE HAUL).	JOB COMPLETED JUNE 1986. CONTRACTOR PAID APPROXIMATELY $1,000,000 ON CLAIM.	50 TO 4,250 POUND RIPRAP WITH LESS THAN 5% MINUS 50 POUND FRAGMENTS (STRICT GRADATION).	REX WYBORNEY (GEOLOGIST) AND LEROY MIKKES (INSPECTOR)	RIPRAP REMAINS IN EXCELLENT SHAPE AFTER BEING IN PLACE ALONG THE BANKS OF THE COLUMBIA RIVER FOR GENERALLY LESS THAN ONE YEAR. RECORDS OF EARLIER PLACEMENT OF THIS TYPE OF ROCK SHOW EVIDENCE OF EXCEPTIONAL ENDURANCE.	RIPRAP PRODUCTION WAS CONTROLLED UNDER STRICT SPECIFIED GRADATION REQUIREMENTS. PERIODIC TESTS WERE TAKEN TO INSURE THAT RIPRAP REMAINED WITHIN SPECIFIED GUIDELINES. SURFACE WEATHERING OF ROCK AND THE PRESENCE OF SMALL SHEAR ZONES HAD REDUCED THE YIELD OF THE QUARRY. ESTIMATED RIPRAP PRODUCTION IN FRESH COMPETENT GRANITE WAS 50% TO 60%.

[illegible] JOINTING [illegible] THROUGH [illegible] AND [illegible], BEDDING/FOLIATION (TABLE 5-3), AND WEATHERING (W 1 THROUGH W 7)

ESTIMATE HIGH, MODERATE, OR LOW PERCENTAGE OF ROCK BREAKDOWN DURING PROCESSING. IF ROCK BROKE DOWN, WAS IT DUE TO EQUIPMENT, SUCH AS VIBRATING GRIZZLY?

[illegible] UNDERSIZE AND EXCESS OF INTERMEDIATE SIZES OR "B" OVERSIZE AND EXCESS OF INTERMEDIATE SIZES [illegible] BROKEN DOWN BY SECONDARY BLASTING OR IMPACT HAMMERS)

[illegible] GEOLOGY FOR DESIGN AND SPECIFICATIONS OF THE ASSISTANT COMMISSIONER-E & R CENTER DEC. 1981 (REVISED JUNE 1982).

Table 19-3. – Data on igneous rock and riprap quarries.—Continued

DATA ON SEDIMENTARY ROCK AND RIPRAP QUARRIES

COMPILED BY GLENN J. TAUCHER 1985-1987 SHEET 1 OF 3

ECT ARRY	YEAR	ROCK TYPE 1/AND CHARACTERISTICS (JOINTING, BEDDING AND WEATHERING)	INVESTIGATIONS CONDUCTED PRIOR TO QUARRYING (DRILLING-TEST BLASTING) INCLUDE COST	LAB TEST DATA	NEW OR EXISTING QUARRY	DRILLING DATA (ANGLE, SIZE, DEPTH AND SPACING OF SHOTS OR COYOTE HOLES)	BLASTING DATA (EXPLOSIVES, POWDER FACTORS, DELAYS ETC.)	EQUIPMENT USED	BREAKDOWN DURING PROCESSING 2/	PERCENT WASTE (MEASURED OR ESTIMATED)	WASTE INCLUDED "A" OR "B" 3/	WAS WASTE USED FOR OTHER PURPOSES (YES OR NO)? WHAT?	CONTRACTORS ESTIMATE $/TON OR $/YARD AMOUNT PRODUCED HAUL DISTANCE	CONTRACTOR CLAIM (YES OR NO)? AMOUNT	ROCK SIZE REQUIREMENT	DATA FROM	SERVICE RECORD	REMARKS
ERRY	1981	CAMBRIAN MEAGHER LIMESTONE BANDED. CUT BY NUMEROUS CALCITE HEALED JOINTS. ESTIMATED FD-4 TO -5 FRACTURING & W-3 WEATHERING	SURFACE MAPPING LESS THAN $200	SP. G. 2.71 BULKING FACTOR OF WASTE MATERIAL WAS 1.75 (NOT COMPACTED)	NEW	3-4" DIAMETER VERTICAL HOLES ON GENERALLY 6X8' PATTERNS. HOLES DRILLED, FROM 20-40' DEEP	AN-FO WITH DELAYS, 0.4-0.6 LBS/YD³ POWDER FACTORS	DOZER, AIR TRACK DRILL, FRONT END LOADERS, ROCK RAKE, VIBRATING GRIZZLY, HAUL TRUCKS, DRAGLINE, AND BACKHOE	HIGH BREAKDOWN ON VIBRATING GRIZZLY. MODERATE BREAKDOWN IN HAUL	MEASURED 75%	B OVERSIZED USED ON DIKES	YES, PART OF WASTE USED FOR ROCK FILL AND SMALL SIZED RIPRAP IN OTHER AREAS	14,730 TONS AT $5.50/TON 9840 TONS AT $6.00/TON 3200 TONS AT $5.00/TON 520 TONS AT $7.81/TON ALL COSTS INCLUDED 5-10 MILE HAUL	YES, DIFFICULT TO DETERMINE AS COSTS WERE COVERED IN OTHER ROCK HAUL	REASONABLY WELL GRADED FROM 1/10 YD³ (8") TO 1/4 YD³ (24")	C. VOLK (CONSTRUCTION REPRESENTATIVE) & G. TAUCHER (REGIONAL GEOLOGIST)	PORTIONS OF RIPRAP WASHED AWAY DURING SEVERE WIND STORMS IN 1983 & 1984. RIPRAP PLACED ON 2:1 SLOPES	OVERSIZE MATERIAL UP TO 36" ALSO PLACED ON DIKES. RIPRAP WAS SHORT OF 18-24" SIZES. SMALL SIZES OF ROCK OBTAINED WERE IN LARGE PART CAUSED BY THE REFRACTURING OF CALCITE HEALED JOINTS DURING BLASTING AND PROCESSING (MOSTLY ON VIBRATING GRIZZLY). QUARRY PROBABLY NEVER GOT THROUGH UPPER WEATHERED ZONE.
URCHE AR TERIALS Y AKOTA	1984	PERMIAN MINNEKAHTA LIMESTONE BANDED, FD-3 TO -7 FRACTURING & W-3 WEATHERING	NONE BY USBR	LAB REPORT C-615	EXISTING	4" DIAMETER VERTICAL HOLES ON 9X10' PATTERN OR 3" DIAMETER VERTICAL HOLES ON 7X7' PATTERN	AN-FO 2.0 LBS/YD³ POWDER FACTOR	AIR TRACK DRILL, COMPRESSOR, FRONT END LOADERS, DOZER, ROCK RAKE, CRUSHER, AND HAUL TRUCKS	LOW BREAKDOWN AFTER BEING CRUSHED FOR AGGREGATE, RIPRAP SIZED FRAGMENTS ALSO HAD LOW BREAKDOWN DURING HAULING AND PLACING	WASTE IN THIS QUARRY WOULD BE RIPRAP OR FINES. ESTIMATED 5% OF MATERIAL USABLE FOR RIPRAP IN THEIR OPERATIONS	SEE COLUMN AT LEFT	LARGER SIZED WASTE USED FOR RIPRAP	5000 TONS AT $15.65/TON 3000 TONS AT $18.50/TON ALL COSTS INCLUDE A 70 MILE HAUL	NO	0-10% MINUS 100 LBS 60-70% 100-2250 LBS 20-40% 2250-4500 LBS	HILLS MATERIAL (REPRESENTATIVE) & G. TAUCHER (REGIONAL GEOLOGIST)	NO BREAKDOWN IN SIMILAR LIMESTONE RIPRAP ON FACE OF DAM DURING 8YR OPERATION PERIOD. HOWEVER, DUMPED ROCK FALLS ON FLAT FACES (BEDDING PLANES) AND TENDS TO SLIDE DOWN SLOPE	QUARRY PRIMARILY DEVELOPED FOR CRUSHED ROCK. QUARRY WASTE USED FOR RIPRAP ON BELLE FOURCHE DAM REPAIR
DAM GRASS S. NA	BEFORE 1955	MISSISSIPPIAN MADISON LIMESTONE	TEST BLAST COST UNKNOWN	NONE	NEW	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	50% WASTE (TOO SMALL) ONLY SMALL PART OF REMAINING MATERIAL MET LARGER SIZE REQUIREMENTS	N/A	N/A	N/A	N/A	PROBABLY WELL GRADED 6-36"	TIBER DAM REPORT & G. TAUCHER (REGIONAL GEOLOGIST)	N/A	TEST BLASTS AND SMALL QUARRIES DEVELOPED IN THE MADISON LIMESTONE IN NORTHERN WYOMING AND WESTERN MONTANA HAVE GENERALLY PRODUCED AN ABUNDANCE OF SMALLER SIZED FRAGMENTS. THE MADISON HAS SUPPLIED RIPRAP FOR CLARK CANYON AND THE YELLOWTAIL AFTERBAY DAMS IN MONTANA
DO RIVER ORK EE) RDE Y, A		PALEOZOIC LIMESTONE, DOLOMITE AND QUARTZITE	UNKNOWN	UNKNOWN	EXISTING	3" DIAMETER VERTICAL HOLES ON 8-10' CENTERS, HOLES DRILLED TO DEPTHS OF 10, 20, AND 35'	2X8" CARTRIDGE 60% HERCULES UNIGEL AND NITRO CARBO NITRATE	GRIZZLY, DOZER FRONT END LOADER AND HAUL TRUCKS	HIGH DUE TO EQUIPMENT AND OVERLOADING SCREEN	ESTIMATED 35 %	B	YES, SOME ROAD BASE	$3.50-7.20/TON HAUL DISTANCE NOT KNOWN	NO	6" TO 1/2YD³	D. BRANSTETTER (REGIONAL GEOLOGIST) R. MOYES (FIELD ENGINEER) & INSPECTOR REPORTS	UNKNOWN	SPECIFICATION REQUIREMENTS NOT AS STRICT AS THOSE USED FOR RIPRAP ON DAM EMBANKMENTS
OJECT P DAM, OO	1984	MASSIVE BEDDED, HIGHLY JOINTED, UNWEATHERED LIME-STONE	PROBABALY SPENT LESS THAN $1000 IN INVESTIGATIONS	UNKNOWN	NEW	USED 3 METHODS: (1) VERTICAL SHOT HOLES ON 9' CENTERS, 18-21' DEEP: (2) HORIZONTAL SHOT HOLES ON 10' CENTERS, 45' DEEP & (3) COYOTE HOLE 60' LONG WITH 30' SIDE DRIFTS TRENDING LEFT AND RIGHT	UNKNOWN	FRONT END LOADERS, HAUL TRUCKS, DRILLS, COMPRESSORS, ETC.	UNKNOWN	ESTIMATED 50% ON VERTICAL HOLES. ESTIMATED 20-30% ON HORIZONTAL HOLES. NEAR 0% WITH COYOTE HOLE	UNKNOWN	YES, ROCKFILL ON DOWNSTREAM DAM FACE	80,000 TONS AT $3.00/TON INCLUDES HAUL AND PLACEMENT	NO	WELL GRADED 1/2 FT³ TO 1/2 YD³	FINAL CONSTRUCTION REPORT ON RIFLE GAP DAM F. THOMPSON (REGIONAL GEOLOGIST)	UNKNOWN	
REEK CT. OMA	1978 TO 1979	PENNSYLVANIAN ATOKA FORMATION WELL TO MODERATELY CEMENTED SANDSTONE AND SILTSTONE WITH INTERBEDDED SHALE THAT DIPS 35° TO THE SOUTHEAST. SANDSTONE AND SILTSTONE COMPRISE 57% AND SHALE 43% OF THE DEPOSIT. CUT BY NORTHEAST AND NORTHWEST TRENDING HIGH ANGLE JOINTS	8 ANGLE NX-SIZE CORE HOLES FROM 80-175' DEEP DRILLED AT TWO SOURCES (SITE IN PENNSYLVANIAN JACKFORK SANDSTONE ABANDONED BECAUSE OF BETTER ROCK IN ATOKA) CORE DRILLING COST = $100,000. TEST BLAST COSTS NOT DETERMINED	SP. G. AVERAGED 2.51-2.55. ABSORPTION AVERAGED 2.25-3.01%	NEW TEST BLAST	151 - 3" DIAMETER VERTICAL AND ANGLE SHOT HOLES RANGING FROM 11.5-26.9' DEEP. SHOT HOLES ON IRREGULAR PATTERNS BUT GENERALLY SPACED FROM 2-3 METERS APART	2-1/2X16" STICKS OF ATLAS POWERDOWN 5 EXPLOSIVES, PRIMERS AND DELAYS. 3-16' OF STEMMING IN HOLES POWDER FACTORS RANGED FROM 0.88-1.63 LBS./YD³	CAT D8K TRACTOR WITH HYDRAULIC DOZER, CAT 988 LOADER, CAT 12F MOTOR PATROL, GARDNER-DENVER PR 123 TRACK MOUNTED WAGON DRILL, TRAILER MOUNTED GARDNER-DENVER 600 COMPRESSOR AND ROCK RAKE	NOT RECORDED	MEASURED 40%. DOES NOT INCLUDE STRIPPING OF SOIL AND WEATHERED ROCK. THIS AMOUNTED TO 20% OF THE QUARRY EXCAVATION. ONLY VERY LIMITED SHALE HORIZONS INVOLVED IN TEST BLAST.	WASTE INCLUDED UNDERSIZE ONLY	TESTED FOR USE IN ZONED EMBANKMENT	NO ESTIMATE	NO	1/2 FT³ TO 1 YD³	REPORT TITLED, MCGEE CREEK PROJECT, OKLAHOMA QUARRY SITE INVESTIGATIONS - JAN. 1980 & JOE JACKSON (REGIONAL GEOLOGIST)	NOT AVAILABLE	REQUIRED SELECTIVE QUARRYING TO SEPARATE SANDSTONE AND SILTSTONE FROM SHALE
T CREEK TAH NO. 1	1974	PERMIAN AND PENNSYLVANIAN OQUIRRH LIMESTONE, FD-3 TO -7 (MOSTLY FD-5) FRACTURE DENSITY, CLOSE TO MODERATE (0.5-3') JOINT SPACING, 0-1 TO -3 OPENNESS THINLY BEDDED TO MEDIUM BEDDED, AND W-3 TO -4 WEATHERING	NONE	SP. G. 2.56-2.61	NEW	VERTICAL HOLES ON 10-12' CENTERS. HOLES DRILLED TO DEPTHS RANGING FROM 3-32'. HOLE SIZE UNKNOWN	NICONATE (PRILL) POWDER FACTOR UNKNOWN	DOZER, FRONT END LOADER, HAUL TRUCKS, DRILL, AND OTHER EQUIPMENT	ESTIMATED MODERATE	MEASURED 72%	A INCLUDES A LARGE AMOUNT OF UNDERSIZE MOSTLY DUE TO FRACTURING, WEATHERING AND SHOOTING	NO	29,500 YDS AT $5.50/YD (INCLUDES 36 MILE HAUL)	NO	12" THICKNESS: 20-40% 250-500 LBS, 60-70% 15-250 LBS, AND 0-10% LESS THAN 15 LBS. 24" THICKNESS: 20-40% 625-1250 LBS, 60-70% 50-625 LBS, AND 0-10% LESS THAN 50 LBS. 36" THICKNESS: 30-40% 225-4500 LBS, 60-70% 100-2550 LBS, AND 0-10% LESS THAN 100 LBS.	N. DEMING (PROJECT GEOLOGIST)	NO VISIBLE BREAKDOWN AFTER 8YRS; HOWEVER ONLY PART OF THE ROCK HAS BEEN UNDER WATER DURING THIS PERIOD.	

POSSIBLE, DESCRIBE JOINTING (FRACTURE DENSITY FD-1 THROUGH -9,^{4} OPENNESS 0-0 THROUGH -5^4, AND FILLING); BEDDING/FOLIATION (TABLE 5-3^4); AND WEATHERING (W-1 THROUGH -7^4)

STIMATE HIGH, MODERATE OR LOW PERCENTAGE OF ROCK BREAKDOWN DURING PROCESSING. IF ROCK BROKE DOWN, WAS IT DUE TO EQUIPMENT, SUCH AS A VIBRATING GRIZZLY?

(OVERSIZE, UNDERSIZE AND EXCESS OF INTERMEDIATE SIZES) OR "B" (UNDERSIZE AND EXCESS OF INTERMEDIATE SIZES-OVERSIZE BROKEN DOWN BY SECONDARY BLASTING OR IMPACT HAMMERS).

OLOGY FOR DESIGN AND SPECIFICATIONS OF THE ASSISTANT COMMISSIONER E & R CENTER, DEC. 1981 (REVISED JUNE 1982).

Table 19-4. – Data on sedimentary rock and riprap quarries.

DATA ON SEDIMENTARY ROCK AND RIPRAP QUARRIES

COMPILED BY GLENN J. TAUCHER 1985-1987

SHEET 2 OF 3

OJECT QUARRY	YEAR	ROCK TYPE 1/ AND CHARACTERISTICS (JOINTING, BEDDING AND WEATHERING)	INVESTIGATIONS CONDUCTED PRIOR TO QUARRYING (DRILLING-TEST BLASTING) INCLUDE COST	LAB TEST DATA	NEW OR EXISTING QUARRY	DRILLING DATA (ANGLE, SIZE, DEPTH AND SPACING OF SHOTS OR COYOTE HOLES	BLASTING DATA (EXPLOSIVES, POWDER FACTORS, DELAYS ETC.)	EQUIPMENT USED	BREAKDOWN DURING PROCESSING 2/	PERCENT WASTE (MEASURED OR ESTIMATED)	WASTE INCLUDED "A" OR "B" 3/	WAS WASTE USED FOR OTHER PURPOSES (YES OR NO)? WHAT?	CONTRACTORS ESTIMATE $/TON OR $/YARD AMOUNT PRODUCED HAUL DISTANCE	CONTRACTOR CLAIM (YES OR NO) ? AMOUNT	ROCK SIZE REQUIREMENT	DATA-FROM	SERVICE RECORD	REMARKS
ER CREEK UTAH RY NO. 2	1979	PERMIAN AND PENNSYLVANIAN OQUIRRH LIMESTONE FD-3 TO -7 (MOSTLY FD-5) FRACTURE DENSITY: CLOSE TO MODERATE (0.5 TO 3.0 FT.) JOINT SPACING, 0-1 TO -3 OPENNESS, THINLY BEDDED TO MEDIUM BEDDED AND W-3 TO -4 WEATHERING	NONE	SP. F. 2.47 TO 2.61	NEW QUARRY ADJACENT TO CURRANT CREEK QUARRY NO.1	3-IN DIAMETER VERTICAL (SEVERAL INCLINED AT 45°) HOLES ON 10 FT CENTERS HOLES 19 TO 50 FT. DEEP.	HERCO MIX (PRILL WITH DYNAMITE (75%), POWDER FACTOR RANGED FROM 0.75 LBS/YD^3 AT THE START TO 0.37 LBS/YD^3 LATER IN THE OPERATION.	STATIONARY GRIZZLY, DOZER FRONT END LOADERS, HAUL TRUCKS, DRILL ETC	MODERATE	ESTIMATED 70%	UNKNOWN	NO	41,800 TONS AT $16.37/TON 22,400 TONS AT $14.64/TON PRICES INCLUDE 20 MILE HAUL	NO	24-IN THICKNESS 30-40% 625-1250 LBS 60-70% 50-625 LBS AND 0-10% LESS THAN 50 LBS. 36-IN THICKNESS 30-40% 2250-4500 LBS. 60-70% 100-2250 LBS. AND 0-10% LESS THAN 100 LBS.	M. DEMING (PROJECT GEOLOGIST)	N/A	
FLEET ZACK) DAM	1979 '	PENNSYLVANIAN MORGAN LIMESTONE FD-5 TO -8 FRACTURE DENSITY FROM 0 TO 15 FT. AND FD-1 TO -4 FRACTURE DENSITY FROM 15 TO 50 FT. MODERATELY TO WIDELY SPACED (1-6 FT) JOINTS BELOW 15 FT; 0-2 TO -4 OPENNESS; THINLY TO THICKLY BEDDED W-4 TO -6 WEATHERING 0-15 FT. AND W-2 TO -3 WEATHERING 15-50 FT.	NONE	SP. G. 2.88	EXISTING	VERTICAL HOLES NO OTHER DATA AVAILABLE	PRILL 0.31 LBS/YD^3 POWDER FACTOR	DOZER, FRONT END LOADERS WITH ROCK BUCKET, DRILL, HAUL TRUCKS ETC.	MODERATE	ESTIMATED AND MEASURED 61%	B	CONTRACTOR WAS ALLOWED TO USE 8% OF THE WASTE AS RIPRAP	100 TONS OF 12-IN. AT $15.40/TON 5,100 TONS OF 18-IN. AT $13.20/TON. 900 TONS OF 24-IN. AT 15.40/TON. 107,800 TONS OF 36-IN. AT $9.00/TON. PRICES INCLUDE 12 MILE HAUL.	YES	18-IN THICKNESS 30-40% 250-500 LBS 60-70% 15-250 LBS AND 0-10% LESS THAN 15 LBS 24-IN THICKNESS 30-40% 625-1250 LBS. 60-70% 50-625 LBS. AND 0-10% LESS THAN 50 LBS. 36 IN THICKNESS 30-40% 2250-4500 LBS. 60-70% 100-2250 LBS 0-10% LESS THAN 100 LBS.	M. DEMING (PROJECT GEOLOGIST)	NO VISIBLE BREAKDOWN AFTER 5 YEARS OF OPERATION.	
N BUTTES DAM N ANGELO, AS		LIMESTONE IN 1 TO 3 FT. BEDS WITH INTERBEDS OF MARL, MINOR VERTICAL JOINTING	CORE DRILLING ESTIMATED $5000 COST	UNKNOWN	NEW	UNKNOWN	UNKNOWN	UNKNOWN	MODERATE	ESTIMATED 40%	UNKNOWN	NO	UNKNOWN	NO	1/2 FT^3 TO 1YD^3	JOE JACKSON (REGIONAL GEOLOGIST) & FINAL CONSTRUCTION REPORT	UNKNOWN	
ANTLEY DAM ANTLEY OJECT W MEXICO		DOLOMITE	TEST BLAST COST ESTIMATED AT $12000	UNKNOWN	NEW	4 IN DIAMETER VERTICAL HOLES ON 6 TO 8 FT CENTERS, HOLES 10 TO 12 FT DEEP	DEFAGEL 1.2 TO 2.5 LBS/YD^3 POWDER FACTOR	STATIONARY GRIZZLY, FRONT END LOADERS, DRILL, ETC.	UNKNOWN	ESTIMATED 55 TO 70%	UNKNOWN	UNKNOWN	UNKNOWN	UNKNOWN	1/2 FT^3 TO 1 YD^3	JOE JACKSON (REGIONAL GEOLOGIST) & PROJECT FILES	UNKNOWN	
BUCKLE DAM BUCKLE OJECT LAHOMA		LIMESTONE	GEOLOGIC RECONNAISSANCE	UNKNOWN	NEW	UNKNOWN	UNKNOWN	VIBRATING GRIZZLY, FRONT END LOADERS DOZER, DRILL, ETC.	UNKNOWN	ESTIMATED 40%	UNKNOWN	YES CRUSHED FOR BEDDING	UNKNOWN	NO	1/2 FT^3 TO 1YD^3	JOE JACKSON (REGIONAL GEOLOGIST) FILES AND CONSTRUCTION SPECIFICATIONS	UNKNOWN	
NSAS CITY OOD CONTROL GENTINE AND MOURDALE UNIT NSAS RIVER, NSAS ORPS OF GINEERS	1953 ?	WINTERSET, BETHANY FALLS, RAYTOWN, ARGENTINE, AND FARLEY LIMESTONES	GRADATIONS (PERCENT PASSING) OF ROCK FRAGMENTS PRODUCED IN TEST BLASTS CONDUCTED IN VARIOUS LIMESTONES ALONG THE KANSAS RIVER												SEE REMARKS	GRADATION CURVES SUPPLIED BY STEVE MARKWELL (EPRC GEOLOGY)	UNKNOWN	THE GRADATIONS LISTED SHOW THE ROCK SIZES PRODUCED AT EACH TEST BLAST CONDUCTED IN THE LIMESTONE DEPOSITS INDICATED. NO INFORMATION IS AVAILABLE ON HOLE SIZE AND SPACING, EXPLOSIONS, POWDER FACTOR, GEOLOGY, EQUIPMENT ETC. SIZE REQUIREMENTS ARE ALSO UNKNOWN EXCEPT FOR THE FIVE BETHANY FALLS LIMESTONE DEPOSITS INDICATED BY A DOUBLE ASTERIK (**). THESE TEST SHOTS WERE INTENDED TO MEET A GRADATION THAT INCLUDED 0% OVER 300 LBS, PLUS 40% OVER 150 LBS. PLUS 80% OVER 10 LBS, AND MINUS 4% UNDER 1/2-IN SIZE.
NYON FERRY ES DERSBURG ARRY NTANA	1984 1985	CAMBRIAN PILGRIM LIMESTONE BEDDING DIPS 90°, MEDIUM BEDDED (1 TO 3 FT) ON UPPER PLATE OF THRUST FAULT, LIGHTLY WEATHERED (W-3); MODERATELY HARD TO HARD (H-4 TO -5) CUT BY VERTICAL JOINTS NORMAL TO BEDDING, LIGHTLY/VERY LIGHTLY TO INTENSELY/ MODERATELY FRACTURED (FD-2 TO-6 AND AVERAGES FD-4). CONTINUED ON SHEET 3 OF 3	6-NX SIZE CORE HOLES RANGING FROM 41 TO 92 FT. IN DEPTH (4 VERTICAL AND 2 HORIZONTAL), GEOLOGIC MAPPING, AND DISCUSSIONS WITH PREVIOUS QUARRY OPERATOR. ESTIMATED COST OF $20,000 FOR DRILLING.	NONE	EXISTING QUARRY WORKED PREVIOUSLY BY S.C.S. 2000 YDS^3 OF ROCK REMOVED FOR STABILIZATION OF MISSOURI RIVER BANK NEAR TOWNSEND, MONTANA	3-IN. DIAMETER VERTICAL HOLES ON 8 X 8, 8 X 9 AND 9 X 10 FT. CENTERS. MOST HOLES ABOUT 25-FT. DEEP	AN-FO WITH OCCASIONAL DELAYS.	DOZER, FRONT END LOADER WITH ROCK BUCKET, TRACK MOUNTED DRILL COMPRESSOR, HAUL TRUCKS AND LARGE BACKHOE	LOW	MEASURED 60% FIGURE INCLUDES MINOR AMOUNTS OF USEABLE ROCK THAT WAS WASTED AT THE DIKE TOE AFTER RUNNING OVER GRIZZLY, AND SOME ROCK LEFT IN THE QUARRY.	B ESTIMATED 10% OF ROCK IN QUARRY SHOTS WERE OVERSIZED AND WERE BROKEN DOWN BY SECONDARY BLASTING.	IT IS ANTICIPATED THAT PART OF WASTE WILL BE USED BY LOCAL IRRIGATION UNIT IN THE FUTURE	1780 TONS OF 24 IN.MAX. ROCK AT $11.50/TON 23,850 TONS OF 36 IN.MAX. ROCK AT $11.80/TON PRICES INCLUDES 13 TO 14 MILE HAUL.	YES, RECEIVED IN JUNE OF 1987.	36-IN LAYER 100% MINUS 3500 LBS, 80-95% PASSING 3000-LBS. 35-50% PASSING 770 LBS. 10-20% PASSING 150 LBS, AND 0-5% PASSING 100 LBS 24-IN LAYER MAXIMUM 500 LBS 30-40% 250 TO 500 LBS 60-70% 15 TO 250 LBS AND 0 TO 10% MINUS 15 LBS.	G. TAUCHER (REGIONAL GEOLOGIST) B. McCORMICK (ENGINEER) AND C. VOLK (INSPECTOR)	EXCELLENT. NO NOTICEABLE BREAKDOWN ALONG RIVER BANK AFTER BEING IN PLACE FOR ABOUT 10 YEARS. NO BREAKDOWN ON DIKES AFTER BEING IN PLACE FOR 2 YEARS.	

GRADATIONS (PERCENT PASSING) OF ROCK FRAGMENTS PRODUCED IN TEST BLASTS CONDUCTED IN VARIOUS LIMESTONES ALONG THE KANSAS RIVER

WEIGHT IN LBS.	WINTERSET	WINTERSET	WINTERSET	RAYTOWN	FARLEY	ARGENTINE & FARLEY	ARGENTINE	ARGENTINE	ARGENTINE	BETHANY FALLS	BETHANY FALLS **	BETHANY FALLS **	BETHANY FALLS **	BETHANY FALLS **	BETHANY FALLS **
600	97	77	100	100	97	100	85	100	78						
500	97	75	86	97	93	96	84	96	71		100				
400	94	70	90	92	88	90	83	93	63		90				
300	90	62	74	86	82	74	80	90	55	92	77	93	96	93	90
200	83	47	64	78	76	65	72	84	45	90	63	81	90	88	86
100	76	32	56	67	62	56	58	73	33	84	47	63	79	82	78
50	67	25	52	56	42	51	47	67	24	76	36	46	69	67	69
10	52	14	38	33	21	35	28	51	11	56	17	28	47	48	54
1	37	5	18	17	8	16	15	36	3	33	7	16	30	34	41
0.1	24	2	10	8	4	10	10	23	1	19	4	10	18	22	27
0.01	11	1	3	5	2	6	7	13	1	8	1	3	7	9	13

1/ IF POSSIBLE, DESCRIBE JOINTING (FRACTURE DENSITY FD-1 THROUGH -9,* OPENNESS -0-0 THROUGH -5*, AND FILLING); BEDDING/FOLIATION (TABLE 5-3*), AND WEATHERING (W-1 THROUGH -7*)

2/ ESTIMATE HIGH, MODERATE OR LOW PERCENTAGE OF ROCK BREAKDOWN DURING PROCESSING. IF ROCK BROKE DOWN, WAS IT DUE TO EQUIPMENT, SUCH AS A VIBRATING GRIZZLY?

3/ "A" (OVERSIZE, UNDERSIZE AND EXCESS OF INTERMEDIATE SIZES) OR "B" (UNDERSIZE AND EXCESS OF INTERMEDIATE SIZES-OVERSIZE BROKEN DOWN BY SECONDARY BLASTING OR IMPACT HAMMERS).

* GEOLOGY FOR DESIGN AND SPECIFICATIONS OF THE ASSISTANT COMMISSIONER E & R CENTER. DEC. 1981 (REVISED JUNE 1982).

Table 19-4. – Data on sedimentary rock and riprap quarries—Continued.

DATA ON SEDIMENTARY ROCK AND RIPRAP QUARRIES

COMPILED BY GLENN J. TAUCHER 1985-1987 SHEET 3 OF 3

PROJECT OR QUARRY	YEAR	ROCK TYPE 1/ AND CHARACTERISTICS (JOINTING, BEDDING AND WEATHERING)	INVESTIGATIONS CONDUCTED PRIOR TO QUARRYING (DRILLING-TEST BLASTING) INCLUDE COST	LAB TEST DATA	NEW OR EXISTING QUARRY	DRILLING DATA (ANGLE, SIZE, DEPTH AND SPACING OF SHOTS OR COYOTE HOLES	BLASTING DATA (EXPLOSIVES, POWDER FACTORS, DELAYS ETC.)	EQUIPMENT USED	BREAKDOWN DURING PROCESSING 2/	PERCENT WASTE (MEASURED OR ESTIMATED)	WASTE INCLUDED "A" OR "B" 3/	WAS WASTE USED FOR OTHER PURPOSES (YES OR NO)? WHAT?	CONTRACTORS ESTIMATE $/TON OR $/YARD AMOUNT PRODUCED HAUL DISTANCE	CONTRACTOR CLAIM (YES OR NO)? AMOUNT	ROCK SIZE REQUIREMENT	DATA FROM	SERVICE RECORD	*REMARKS
ADERSBURG ARRY NTINUED		TIGHT TO PARTLY OPEN (O-0 TO 1-0), SOME CLAY SEAMS ENCOUNTERED ON WEST SIDE OF QUARRY, 88% CORE RECOVERY, 69% RQD CORE LENGTHS - 43% MINUS 1-FT, 31% 1 TO 2-FT, 9% 2 TO 3-FT. AND 17% PLUS 3-FT.																
ANYON FERRY KES ESTON UARRY, ONTANA	1985-1986	CAMBRIAN PILGRIM LIMESTONE BEDDING DIPS 20-30° MEDIUM TO THICKLY BEDDED (1 TO 5-FT.), LIGHTLY WEATHERED (W-3), HARD (H-3), MODERATELY SPACED JOINTS (1 TO 3-FT.), SOME JOINTS OPEN TO 3-IN. & CLAY FILLED	NONE CONTRACTOR SELECTED THIS QUARRY BASED ON RADERSBURG QUARRY	NONE	NEW	FINAL SHOT PATTERNS CONSISTED OF 3-IN. DIAMETER VERTICAL HOLES ON 8 x 11 FT. SPACING, DECKED LOADS WITH EACH ROW DELAYED, 30-40-FT. HOLE DEPTHS.	TWO DECKS (DRILL & PRIMER) LOADED PER HOLE AT STAGGERED ELEVATIONS 0.8 LBS./YD³ POWDER FACTOR	STATIONARY GRIZZLY (SLOPE OF GRIZZLY WAS 1 1/2 TO 1 W/ 2 1/2" BARS SPACED ON 18" CENTERS) CRANE W/WRECKING BALL, 2 AIR TRACKS, 2 FRONT END LOADERS, DOZER, 2 BACKHOES & 16 TRUCKS	LOW	WASTE INITIALLY WAS 70% BUT WAS REDUCED TO 45% BY CHANGING BLASTING AND BREAKING OVERSIZE. TOTAL WASTE IN QUARRY OPERATIONS WAS ESTIMATED AND MEASURED TO BE ABOUT 55%.	B WASTE FIGURES BASED ON BREAKING DOWN OVERSIZE.	NO, BUT STOCKPILED FOR POTENTIAL USE	PLACED 148,500 TONS OF RIPRAP AT COST OF $2,190,000 OR $14.75/TON. THIS INCLUDED A HAUL OF ABOUT 30 MILES.	NO	100% PASSING 4000 LBS.; 80-100% PASSING 3000 LBS 35-50% PASSING 770 LBS.; 10-20% PASSING 50 LBS.	G.TAUCHER (REGIONAL GEOLOGIST) B. McCORMICK (ENGINEER)	NO BREAKDOWN ON DIKE AFTER 1 YEAR	
OLORADO EY QUARRY ORTH OF T. COLLINS, OLORADO	1987	PENNSYLVANIAN INGLESIDE FORMATION (CALCAREOUS AND SILICEOUS SANDSTONE)	NONE BY USBR	LA ABRASION (500 REVOLUTIONS) 30% LOSS IN UPPER 12' AND 42% LOSS IN LOWER UNIT.	EXISTING COMMERCIAL QUARRY	UNKNOWN	UNKNOWN	UNKNOWN	PROBABLY LOW TO MODERATE	ESTIMATED 50%	A	YES	$8.25/TON FOR WELL GRADED 6 TO 30-IN. DIAMETER ROCK AT PLANT.	—	—	SEE REMARKS	—	DATA BASED ON ESTIMATES FROM PAUL HAERR CHAIRMAN OF COLORADO LIEN (APRIL 1987)

1/ IF POSSIBLE, DESCRIBE JOINTING (FRACTURE DENSITY FD-1 THROUGH -5*, OPENNESS -0-0 THROUGH -5*, AND FILLING) BEDDING/FOLIATION (TABLE 5-2*) AND WEATHERING (W-1 THROUGH -7*)

2/ ESTIMATE HIGH, MODERATE OR LOW PERCENTAGE OF ROCK BREAKDOWN DURING PROCESSING. IF ROCK BROKE DOWN, WAS IT DUE TO EQUIPMENT, SUCH AS A VIBRATING GRIZZLY?

3/ "A" (OVERSIZE, UNDERSIZE AND EXCESS OF INTERMEDIATE SIZES) OR "B" (UNDERSIZE AND EXCESS OF INTERMEDIATE SIZES-OVERSIZE BROKEN DOWN BY SECONDARY BLASTING OR IMPACT HAMMERS)

* GEOLOGY FOR DESIGN AND SPECIFICATIONS OF THE ASSISTANT COMMISSIONER E & R CENTER, DEC. 1981 REVISED JUNE 1982)

Table 19-4. - Data on sedimentary rock and riprap quarries—Continued.

Chapter 20
DATA COLLECTION FOR GROUTING

Introduction

This chapter provides information for the field geologist and for those individuals who are not familiar with Reclamation methods of data collection for the design of a functional grout curtain. It incorporates the existing methods used for pressure testing (above and below water level), pump-in tests and pump-out tests.

Readers should be familiar with or at least aware of ACER Technical Memorandum No. 5, "Policy Statements for Grouting," 1984. Policies, grouting terms, procedures, and value engineering are discussed. Other useful references are listed at the end of this chapter.

Site Geology

Ascertain the site geology and determine the basic rock types. Sedimentary rocks require different treatment than metamorphics or igneous rocks. Caution is required in dealing with sedimentary rocks because of possible soluble layers—for example, gypsum and anhydrite. Limestones and dolomites also are subject to solutioning. Vertical or high angle joints are widened by solutioning and may become filled with clay. One should be alert for caves, solution cavities, or caverns.

Metamorphic rocks such, as schists or gneiss, are subjected to fracturing by tectonic activity. Joints and schistosity require close observation throughout drilling and water testing so a suitable grouting design can be made.

Igneous rocks also require close observation. Varying degrees of weathering from fresh to decomposed, jointing, flow contacts, even glassy characteristics, must be recorded so that chemical reactivity with cement (grout) can be countered.

Many other details can be useful for the grout curtain design. However, if the criteria established in the Engineering Geology Office Manual and Chapter 10 this Field Manual are used, a successful grout curtain can be designed.

Literature Search

Frequently a dam is only a part of a major project. Features that often are associated with a dam are canals, tunnels, pipe lines, pumping plants, power plants and switch yards. Depending on the sequence of construction, varied amounts of data become readily available. These data usually are recorded in the construction report for that feature. Rock characteristics which can affect the design of the grouting program and derived from one feature probably can be related to another feature within the project vicinity, if the geologic setting is similar. Therefore, the principal geologist should package data for use by the principal designer in the design of the grouting. Both should work together to obtain a suitable design for the grout curtain.

Several earth and concrete dams are listed in the ACER Technical Memorandum No. 5, with grouting criteria for those dams.

Geologic Structure

This discussion is based on data collection methodology presented in the Engineering Geology Office Manual and Part I of this manual. It is emphasized that if data collected are always of the highest quality, and if the established criteria are followed and interpreted properly, then each of the following will fall into place.

Determine the structure. Jointing and jointing characteristics will have a great influence on the grouting design. Determine the major and minor joint sets, and bedding or foliation. Provide dip and strike, spacing or thickness of the foliation or bedding, joint openness, the filling or healing of those openings and the nature of filling materials, and determine the depths of the openness, filling and filling materials.

Shears, faults, and other discontinuities also will influence the design of a workable grout curtain. Determine the strike and dip, the relationship to other structure(s), the continuity length and thickness of the disturbed zone, the openness, filling or healing and the effects of depth on the geologic discontinuity.

Folding, bending and buckling should be determined. Their relationship to other geologic structures, if any, should be determined. How will the geology affect the dam or other structures? Regardless of rock type, determine the possibility of seepage, rebound, subsidence or collapse.

Data collection for various grout curtains may become repetitive. However, geology usually changes between the valley floor and abutments, or other appurtenant structures. It is better to have adequate data for proper design than to have too little and risk being faced with a claim for changed geologic conditions. One small claim can equal or exceed the cost of several drill holes and suitable testing.

Geohydrology

Almost all engineering projects are affected by subsurface water. The importance of subsurface water is obvious, especially in respect to water retention structures. A thorough understanding of the regional and site specific ground-water conditions is necessary to safely design, construct, and operate these projects. Application of the principles to specific problems such as foundation treatment and grouting then can be determined.

1. Porosity and Hydraulic Conductivity.—Almost all rock contains pore spaces to some extent. To be permeable, pore spaces in rock must be interconnected and sufficiently large to allow the passage of water. Most sandstones are both porous and permeable. Shale, on the other hand, has a high porosity but the pores are limited to capillary sizes and water passage through the shale is extremely slow. Although intact shale is porous but impermeable, joints and other fractures permit the passage of water even though the water cannot readily pass through the interior of the joint-bounded rock. Even where the bedrock is massive and impermeable, water

occurs in fractures to some depth. Understanding the nature of the joint system is of crucial importance in these areas. It is important to determine primary and secondary permeabilities, if possible.

2. Ground water.

a. Ground water is the water in the zone of saturation. The upper limit of this zone is referred to as the water table. The depth to the water table may vary considerably depending on site conditions. The ground water may be found either in continuous bodies or in several separate strata, and the thickness may vary considerably. Local saturated zones (perched water) occur above the main water table.

b. Local geology, permeability of the formations, including solutioning and fracturing, and recharge and movement within the zone are factors that affect acquifer characteristics. The hydraulic pressure at any level in an unconfined aquifer is the same as the depth from the water table to the subject depth and may be expressed as hydraulic head in feet of water. In a confined aquifer, water under artesian conditions is under hydrostatic pressure and therefore rises in a well.

c. Artesian water also occurs in a similar fashion in jointed bedrock. Certain sets of joints may be more open, and a large amount of water may collect in the joints under artesian conditions. A drill may pass through a few hundred feet of impermeable rock in which the joints are few and tight. When the open-jointed zone is reached, the hydrostatic pressure at that depth causes the water to rise. The number of joints, as well as the degree of openness, normally decreases with depth, and the chance of penetrating a water-bearing zone is generally greatest in the upper portion of the bedrock.

3. Springs.—Any natural surface emergence of water from a subterranean source is a spring. Many small springs represent water from rain or snow from higher ground that moves under gravity to a place of emergence. The source and flow rate of a spring depend on the permeability and

structure of the material through which the water moves. Some springs flow upward with a measurable force, indicating that they are under pressure. Springs are most common in sandstones, cavernous carbonate rocks, vesicular lava flows, and highly jointed or fractured rocks of any kind. Some of the largest springs develop along the borders of karst regions.

4. Water Quality.—The quality of the ground water is due primarily to the mineralogical character of the reservoir rocks and their degree of solubility in water. The ground water in limestone areas usually has a higher content of dissolved carbonates. Rock salt (halite) furnishes a ready source of chlorides, while gypsum and anhydrite supply sulfates. Water containing humic and other acids, dissolved sulfates, chlorides, and similar chemicals, may act corrosively on steel and iron and may be injurous to grout and concrete. Ferrous iron in water may oxidize into an unsightly limonitic stain in certain cases. Iron may lead to development of growths of iron bacteria. The source of the ferrous iron is generally rocks that contain pyrite or marcasite (iron sulfides). These minerals are common in many shales, especially carbonaceous shales. Water from such sources may contain hydrogen sulfide. In areas where coal mining has occurred, both ground and surface water may be highly acidic.

5. Grouting Considerations.—

a. Ground-water conditions have an important effect on design and construction; therefore, the regional and local conditions must be studied during the investigation stages so that potential problems can be evaluated. The grouting program should be designed for the existing ground-water conditions as well as for postconstruction conditions. Different methods and procedures may be employed, depending on the formation permeability, the depth to water table, and the type of grout, the grouting procedure, the depth and extent of treatment, the spacing of holes, the need for a multiple- or single-line grout curtain, and the pressures that should be used.

b. Aquifer conditions have a direct bearing on the need for and type of drainage required. The chemistry of the ground water should be considered with respect to the materials to be used in the proposed structure and to the grout to be used. Samples should be tested for pH and the chemistry analyzed (Stiff diagrams). Springs in the construction area may require special treatment, including special grouting methods.

Investigation Methods

1. Background.

a. Investigations for grouting design must be oriented toward identifying both the normal and the abnormal conditions and the discontinuties of even the smallest degree, because these conditions may control the design of the structure.

Special drilling procedures and equipment may be required to identify the discontinuities and anomalies. Besides the grouting design, the subsurface investigations are used to determine the type and extent of excavation, ground-water conditions, and foundation preparation and treatment required.

b. The type and scope of the drilling program are determined by the type of the proposed project and by the geology. The program should be divided into stages. The phased or staged investigation may emphasize certain geologic features, such as stratigraphy and structure, ground-water investigations, and foundation analysis. Therefore, a variety of investigative methods may be required.

These may include seismic and electrical resistivity surveys, core holes of various standard sizes, noncored holes, calyx holes for in situ foundation inspection, downhole logging techniques, swab tests, pump tests, pressure tests, and borehole photography. Each hole drilled should be designed to give the maximum amount of information possible that is pertinent to the situation.

2. Site Conditions.—Since grouting and drainage requirements and procedures are based primarily on geological con-

ditions at a particular site and proposed structure, the exploration program must be comprehensive and accurate. If investigations confirm the presence of certain adverse geological conditions, treatment by excavation or grouting, or even relocation of the site, may need to be considered. The adverse conditions may include such things as the presence of soluble rocks, evidence of solution activity, prominent open joints, intensely fractured rock, jointing, open bedding planes, faulting, or unusual ground-water conditions. Field mapping of the formations should be made at the site, if possible, and at nearby outcrops to get a feel for joint and fracture spacing, continuity, and openings. Supplementary information should be obtained from drilling at the site as described below.

3. Drilling.—Specific information on subsurface conditions is needed to plan the grouting program. To determine the scope and to estimate the costs of drilling and grouting operations in rock, information should be available on: overall geologic structure and stratigraphy; orientation, attitude, and spacing of joints; joint openings including characteristics of any filler; boundaries of rock types; location of faults; location of fractured zones; depth to sound rock; and position of water table. Sufficient drilling should be performed to delineate the above features. Tools such as borehole and television cameras and geophysical logging instruments should be used where needed to define subsurface conditions. Extensive use should be made of angle holes to give the maximum information possible concerning high-angle jointing and faulting, particularly on the abutments where sheet or relief joints often occur. Each hole should be pressure tested and/or pumped to determine not only water take but to isolate the water-bearing or open zones in the hole. Therefore, the holes should either be tested as they are drilled or tested by the use of a straddle packer after drilling is completed. If artesian conditions are encountered, these zones should be isolated and tested.

Water Testing

The determination of ground-water conditions at a dam is important to a design analysis for the dam. To gain sufficient knowledge of the hydrologic regime in the dam abutments and foundation, extreme care must be exercised in drilling holes and performing water tests. Whenever possible, standard packers and standard procedures should be used (limiting the pounds per square inch per foot per adequate cover to 0.5 lb/in² [3.5 kPa]). Procedure A is the least desirable, but should be used when pressures cannot be developed. Procedure B is to be used in foundation holes, for the 10- to 50-foot (3- to 15-meter) depth below the base of the buttresses, unless artesian conditions exist. When flow-out measurements can be made, as in Procedures C and D, they are preferable to pump-in tests. Flow-out and pump-in test results from the same interval are desirable, however, to determine if any systematic variations exist between the two methods. Descriptions of the procedures follow:

Procedure A.—For water tests in intervals with less than 25 feet (7.6 meters) of ground cover (50 feet [15.2 meters] below the base of the buttresses for foundation holes) or if the maximum available pump-in rate will not bring the water level near the top of the rods or pipe:

1. Drill a 10-foot (3 meter) section of hole.

2. Clean the hole.

3. Measure and record static water level (natural or from drilling fluid), if any.

4. Measure and record temperature of water to be pumped in.

5. Inject water through small-diameter tubing to below static water level and raise water to a higher stabilized water level, or provide a stabilized water level if no water was originally in the hole.

6. Measure and record stabilized water level and rate of water inflow.

7. Repeat steps 5 and 6 with two higher flows and two higher stabilized water levels. Measure and record stabilized water levels and rates of water inflow.

8. If the stabilized water level in any of the three steps is above the bottom of any casing or cemented interval, record interval of casing or cement, whichever is controlling the bottom of the hole.

9. This procedure also can be used with a seated packer with all measurements made inside the drop pipe.

Procedure B.—For water tests where piezometric level in the rods or pipe is very near collar elevation, either above or below. Follow this procedure if the pressure to limit artesian flows is too low for accurate gauge readings needed for Procedure C or D below.

1. Drill 10-foot section of hole.

2. Clean hole.

3. Measure and record depth to water or rate of total flow from casing.

4. Seat packer. Record packer type and depth and inflated packer pressure. (When seating a packer, use more pressure than the head will apply when the system is full of water). The amount of pressure required on the packer is (a) the desired pumping pressure, plus (b) the static head of the fluid column, plus (c) the energy required to expand the packer.

5. Measure and record rate of flow, (if any), from rods or pipe, or depth to water, and temperature of water in rods or pipe. If flowing add sufficient rod or standpipe to stop flow and measure corresponding elevation.

6. If flow rate or temperature changed from test higher in section, take water samples from rods or pipes for chemical analyses.

7. Measure and record rate of any flow of water from casing.

8. Measure and record stickup of rods or pipe above ground surface.

9. Measure and record temperature of water to be introduced into system.

10. Pour water into the rods or pipe at a steady rate to keep the rods or pipe full. Record the rate of flow and the length of time flow was maintained.

11. Extend the top of the rods or pipe up 5 feet (1.5 meters) and measure and record the new stickup of rods or pipe above ground surface.

12. Repeat step 10.

13. Extend the top of the rods or pipe up 5 more feet (1.5 meters) and measure and record the new stickup of rods or pipe above the ground surface.

14. Repeat step 10.

15. Remove packer from hole.

16. Record total stabilized flow from casing, if any. Also record interval from casing to bottom hole or from cement to bottom hole, whichever is controlling.

Procedure C.—For water tests under low-flow artesian conditions.

1. Drill 10-foot (3-meter) section of hole.

2. Clean hole.

3. Measure and record total rate of flow from casing and water temperature.

4. Seat packer. Record packer type and depth and inflated packer pressure.

5. Measure and record rate of flow of water from rods or pipe, and water temperature.

6. If flow rate or temperature changed from test higher in section, take water sample from rods or pipe for chemical analysis.

7. Measure and record rate of flow of water from casing.

8. Add 5/8- or 3/4-inch (16 or 19 millimeter) flexible hose to rods or pipe.

9. Raise end of hose up until flow no longer occurs. Record that height above ground surface.

10. Lower hose until about one third of the total flow rate, as measured in step 5, flows from hose. After flow stabilizes, record flow and that height above ground surface.

11. Lower hose until about two thirds of the total flow rate, as measured in step 5, flows from hose. Record stabilized flow and that height above ground surface.

12. In select intervals also perform standard pump-in tests using the criteria 0.5 lb/in^2 per foot (3.5 kPa per 0.3 meter) of adequate cover.

13. Remove packer.

14. Record total stabilized flow rate from casing. Also record interval from casing to bottom of hole or from cement to bottom of hole, whichever is controlling.

Procedure D.—For water tests under high artesian conditions.

1. Drill 10-foot (3 meter) section of hole.

2. Clean hole.

3. Measure and record total rate of flow from casing and water temperature.

4. Seat packer. Record packer type and depth and inflated packer pressure.

5. Hook up apparatus and measure and record flow rate of water from rods or pipe, and water temperature.

6. If flow rate or temperature changed from test higher in section, take water sample from rods or pipes for chemical analysis.

7. Measure and record rate of flow of water from casing.

8. Shut system in.

9. Read surface gauge or sandpipe level until pressure stabilizes for two 5-minute intervals. Record pressures.

10. Record rate of flow from casing.

11. Open valve to allow about one third of the rate recorded in step 5 to flow out of rods or pipe until stable for 5 minutes. Record pressure or stand pipe level, flow rate, and total amount of water.

12. Allow about two thirds of the rate recorded in step 5 to flow until stable for 5 minutes. Record pressure, flow rate, and total amount of water.

13. Open the system up to total flow. Record stabilized flow rate and pressure.

14. In select intervals also perform standard pump-in tests using the criteria 0.5 lb/in^2 per foot (3.5 kPa/0.3 m) of adequate cover.

15. Remove packer.

16. Record total stabilized flow rate from casing. Also record interval from casing to bottom of hole or from cement to bottom of hole, whichever is controlling.

Test Grouting

Field grouting tests prior to detailed design are important. They provide the most accurate information for designing the complete grout program and for estimating the quantities to be required. Test grouting can be valuable in evaluating the effectiveness that may be expected from the complete curtain. Test grouting can provide information as to which drilling method is best for the rock formation to be grouted.

A test performed in each different geologic environment that the construction grouting will encounter is advisable if the differences are significant.

The test grouting may range from a very simple test of several different grout mixtures pumped into a few holes to determine the amount of each mix that can be injected, to a comprehensive test that uses observation wells and pump tests before and after to evaluate the effectiveness of the grouting. The type of test selected should be based upon information needed, size of project, and complexity of geologic conditions. The test grouting must be performed by persons having extensive grouting experience along with the Principal Designer and Principal Geologist. Testing should not include rock which will be excavated during the project construction.

Single Line Test Curtain

The simplest grouting test is to drill and grout a line of holes along the proposed grout line. Careful records must be kept of each operation involved in the test. It is advisable to begin the grouting with a thin mixture, such as five parts water to one part cement. Care must be taken not to inject the hole with a mixture that is too thick and will stop the hole prematurely from taking grouting. If this happens, immediately thin the mixture being pumped.

Grouting of one hole is not an adequate grout test. Geologic conditions are far too variable for one hole to be representative. The number of holes used for test grouting must be based on the designer's judgment and knowledge of the geologic conditions, but would include split-spaced holes, (holes spaced equidistant between previously grouted holes).

The main benefit from a single line grout test is to obtain an indication of the amount of grout the formation will take (for quantity-estimating purposes) and optimum primary and split-spacing distances. Also it provides design information on drilling and grouting procedures to use.

Summary

Many rock types have a low primary permeability but a relatively high fracture and joint permeability, the importance of grouting the structural defects is obvious. The type of geologic structural feature (e.g. fault, fold, joint) will dictate the type and extent of excavation treatment and the grouting methods. The spacing and nature of the fractures (e.g. open, weathered, solutioned) influence the type of grout treatment selected, such as consolidation grouting curtain grouting. Fracture characteristics also influence the selection of a single-line or multiple-line curtain and the grout hole spacing.The orientation (dip and strike) of these discontinuities in relation to a designed engineering structure determines the optimum angle and direction of grout holes and drain holes. The depth of the fractures determines the necessary depth of a grout curtain. The grout holes should intersect all the features, and each inclined or vertical feature ideally should be intersected by several holes at different depths. Faults may be gouge-filled and impermeable, thereby forming a barrier, or may be open and carry ground water. Joints may be filled or open, may have weathered or nonweathered faces, and may intersect and be connected over a wide area.The condition of the joints would affect the drilling, the cleaning, the pressure testing, and the grouting of the hole. Since structural features influence the grouting program so profoundly, the site exploration should be sufficiently thorough to base the design on actual site conditions.

Bibliography

Bureau of Reclamation, U.S. Department of the Interior, "Policy Statements for Grouting." ACER Memorandum No. 5, 1984.

Fetzer, C.A., Bureau of Reclamation, U.S. Department of the Interior, "Analysis of the Bureau of Reclamation's Use of Grout and Grout Curtains—Summary," REC-ERC-86-3, February 1986.

Fetzer, C.A., Bureau of Reclamation, U.S. Department of the Interior, "Analysis of Utilization of Grout and Grout Curtains—Hoover Dam," GR-86-2, February 1986.

Fetzer, C.A., Bureau of Reclamation, U.S. Department of the Interior, "Analysis of Utilization of Grout and Grout Curtains—Kortes Dam," GR-86-3, February 1986.

Fetzer, C.A., Bureau of Reclamation, U.S. Department of the Interior, "Analysis of Utilization of Grout and Grout Curtains—Hungry Horse Dam," GR-86-4, February 1986.

Fetzer, C.A., Bureau of Reclamation, U.S. Department of the Interior, "Analysis of Utilization of Grout and Grout Curtains—Flaming Gorge Dam," GR-86-5, February 1986.

Fetzer, C.A., Bureau of Reclamation, U.S. Department of the Interior, "Analysis of Utilization of Grout and Grout Curtains—Morrow Point Dam," GR-86-6, February 1986.

Fetzer, C.A., Bureau of Reclamation, U.S. Department of the Interior, "Analysis of Utilization of Grout and Grout Curtains—Heron Dam," GR-86-7, February 1986.

Bureau of Reclamation, U.S. Department of the Interior, "Pressure Grouting," Technical Memorandum 646, June 1957.

Water Resources Commission N.S.W. Australia, *Grouting Manual,* 1980.

Water Resources Commission N.S.W. Australia, *Manual of Grouting Techniques for Anchor Tendons,* 1978.

Department of the Army, Office of the Chief of Engineers, "Chemical Grouting," EM 1110-2-3504, May 31, 1973.

Department of the Army and the Air Force, "Grouting Methods and Equipment," TM 5-816-6 or AFM 88-32, February 1970.

Department of the Army, Corps of Engineers, Office of the Chief of Engineers, "Grouting Technology," EM 110-2-3506, January 20, 1984.

Department of the Army, U.S. Army Engineer Division, Missouri River, Omaha, Nebraska 68102, (John Albritton), U.S. Army Engineer Division Southwestern, Dallas, Texas 75242 (Lawson Jackson) and George Washington University, Washington D.C. 20006 (Robert Bangert), "Foundation Grouting Practices at Corps of Engineers Dams," Technical Report GL-840-13, October 1984.

U.S. Army Engineer Waterways Experiment Station, "Bibliography on Grouting." Page C-78-8, 1978.

American Society of Civil Engineers, "Proceedings of the Conference on Grouting in Geotechnical Engineering," Edited by Wallace Hayward Baker, February 1982.

Clarke, William J., American Society of Civil Engineers, "Performance Characteristics of Microfine Cement," (preprint 84-023) May 14-18, 1984.

Chapuis, Robert P., Parc, J. Jacques, and Louiselle, André A., "Laboratory Test Results on Self-Hardening Grouts for Flexible Cutoffs," *Canadian Geotechnical Journal*, v. 21, No. 1, pp. 185-191, February 1984.

Bruce, D.A., and C.R.F. George, "Rock Grouting at Wimbleball Dam," *Geotechnique*, 32 No. 4, 323-348.

Grant, Leland F., "Concept of Curtain Grouting Evaluation," *Journal of the Soil Mechanics and Foundations Division*, Proceedings of the American Society of Civil Engineers, January 1964.

Brassington, F.C., and S. Walthall, "Field Techniques Using Borehole Packers in Hydrogeological Investigations," *Quarterly Journal Engineering Geology*, v. 18, pp. 181-193, 1985.

Black, John H., "The Interpretation of Slug Test in Fissured Rocks," *Quarterly Journal Engineering Geology*, v. 18, pp. 161-171, 1985.

Houlsby, A.C., "Routine Interpretation of the Lugeon Water-test," *Quarterly Journal Engineering Geology,* v. 9, pp. 303-313, 1976.

Bruce, Donald A. and James P. Millmore, "Rock Grouting and Water Testing at Klecer Dam, North Umberland," *Quarterly Journal Engineering Geology,* v. 16, pp. 13-29, 1983.

Muller, R.E., "Technical Note—Monitoring of Pumping Tests and Grouting Operations," *Rock Mechanics and Rock Engineering,* v. 17, pp. 51–59, 1984.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

APPENDIX A

ABBREVIATIONS COMMONLY USED IN BUREAU OF RECLAMATION ENGINEERING GEOLOGY (MANY ARE MODIFIED FROM A.A.P.G. COMMITTEE ON STRATIGRAPHIC CORRELATIONS)

Word	Abbreviation
Abundant	abnt
Assistant Commissioner—Engineering & Research	ACER
Agglomerate	aglm
Aggregate	agg
Altered, altering, alternating	alt, altng
Amorphous	amor
Amount	amt
Angular	ang
Anhedral	anhed
Anhydrite, anhydritic	anhy
Aphanitic	aph
Apparent	ap
Appears	aprs
Approximate, approximately	approx
Aragonite	arag
Arenaceous	aren
Argillaceous	arg
Arkose, arkosic	ark
Asphalt, asphaltic	asph
At	@
Auger hole, hand	AH
Auger hole, power	AP
Average	avg
Backhoe trench	BHT
Band, banded	bnd
Barite, baritic	bar
Barrel	bbl
Basalt	bas
Bed	bd

APPENDIX A (continued)

Word	Abbreviation
Bedded	bdd
Bedding	bdg
Bedding joint(s)	BJ(s)
Bentonite, bentonitic	bent
Bifurcating	bifur
Biotite	biot
Bitumen, bituminous	bit
Black	blk
Block, blocky	blky
Blue, bluish	bl
Boulder	bldr
Botryoidal	btry
Breccia, brecciated	brec
Brittle	brit
Bright	bri
Broken	brk
Brown	brn
Calcite, calcareous	cal
Caliche	clce
Carbonaceous	carb
Cavernous, cavity	cav
Casing	cs
Caving	cvg
Cement, cemented	cmt
Center, centered	cntr
Chalcedony	chal
Chalk, chalky	chk
Chert	cht
Cherty	chty
Chloritic, chlorite	chlor
Clastic	clas
Clay	CL or CH
Clayey	cly
Claystone	clyst
Clean	cln
Clear	clr
Cleave	clv
Cleavage	clvg
Close, closely	clo

APPENDIX A (continued)

Word	Abbreviation
Cluster	cls
Coarse, coarsely	c
Cobble	cbl
Columnar	col
Common	com
Compact	cpct
Conchoidal	conch
Concentric	cncn
Concretion, concretionary	conc
Conglomerate	cgl
Contact	ctc
Continuous, continue	cont
Contorted	cntrt
Conquina	coq
Covered	cov
Crenulated	cren
Crevice	crev
Cross-bedded, cross-bedding	xbd xbdg
Cross-laminated	xlam
Cross section	xsec
Cross-stratified	xstrat
Cryptocrystalline	crpxl
Crystal, crystalline	xl
Cuttings	ctgs
Debris	deb
Decomposed	decomp
Decrease, decreasing	decr
Dendritic	dend
Dense	dns
Determine	dtrm
Detrital, detritus	dtrl
Diameter	dia
Difference	dif
Dike	dk
Discontinue	disc
Displaced	disp
Disseminated	dism
Dolomite, dolomitic	dol

APPENDIX A (continued)

Word	Abbreviation
Dozer trench	DT
Drill hole	DH
Drawing	dwg
Elevation	El or EL (SI)
Elliptical	elip
Elongated	elg
Embedded	embd
Enlarged	enl
Equivalent	equiv
Estimated	est
Euhedral	euhed
Evaporatic	evap
Expose, exposed, exposure	exp
Extrusion, extrusive	extr
Faceted	fac
Fahrenheit	F
Faint	fnt
Fair	fr
Fault	flt
Feldspar, felsdpathic	fld
Ferruginous	Fe
Fibrous	fib
Figured	fig
Fine, finely	f
Fissile	fis
Flaky	flk(s)
Flaky	flky
Flat, flattened	flat
Floating	fltg
Fluorescence	flor
Foliated	fol
Foliation joint(s)	FJ(s)
Foot, feet	ft
Formation	fm
Fossil, fossiliferous	fos
Fracture, fractured	frac
Fracture zone	FZ
Fragment, fragmental	frag

APPENDIX A (continued)

Word	Abbreviation
Fresh	frs
Friable	fri
Frosted	fros
Gabbro	gab
Generally	gen
Glassy	gl
Glauconite, glauconitic	glau
Gloss, glossy	glos
Gneiss	gns
Gouge	gou
Grade, grades, graded	grd
Grading	grdg
Grain, grained	gr
Granite	grnt
Granular	gran
Granule	grnl
Gravel	gvl
Gravity	g
Gray	gy
Graywacke	gywke
Greasy	gsy
Green	gn
Gritty	grty
Gypsum, gypsiferous	gyp
Hackly	hky
Hard	hd
Healed	hld
Heavy	hvy
Hematite, hematitic	hem
Hexagonal	hex
High	hi
Horizontal	hor
Igneous	ig
Imbedded	imbd
Impression	imp
Inch	in
Included, inclusion	incl

APPENDIX A (continued)

Word	Abbreviation
Increase, increasing	incr
Indistinct	indst
Indurated	ind
Intensely	int
Interbedded	intbd
Intercalated	intcl
Intercrystalline	intxl
Interfingered	intfr
Intergranular	intgran
Interlaminated	intlam
Interstitial	intstl
Interval	intv
Intraformational	intfm
Intrusion, intrusive	intr
Iron	Fe
Irregular	irr
Irridescent	irid
Jointed	jtd
Joint opening	jt. op.
Joint spacing	jt. sp.
Joint(s)	jt(s)
Kaolin	kao
Laminated	lam
Large, larger	lrg
Lavender	lav
Layer	lyr
Leach, leached	lch, lchd
Ledge	ldg
Lenticular	len
Light, lighter, lightly	lt, ltly
Lignite, lignitic	lig
Limestone	ls
Limonite, limonitic	lmn
Limy	lmy
Liquid limit	LL
Lithic, lithology, lithographic	lith
Little	ltl

APPENDIX A (continued)

Word	Abbreviation
Local, locally, located	loc
Long	lg
Loose	lse
Lower	low
Luster	lstr.
Magnetic	magn
Marlstone	mrlst
Maroon	mar
Massive	mas
Material, matter	mat
Matrix	mtx
Maximum	max
Mechanical break	MB
Median	mdn
Medium	m
Member	mbr
Metamorphic	meta
Mica, micaceous	mica
Microcrystalline	micxl
Middle	mid
Mineral, mineralized	mnrl
Minimum, minute	min
Minor	mnr
Moderate	mod
Mottle, mottling	mot
Mudstone	mdst
Muscovite	musc
Non	n
Nodule	nod
No recovery	NR
Number	no.
Numerous	num
Object	obj
Occasional	occ
Ochre	och
Odor	od
Olive	olv

APPENDIX A (continued)

Word	Abbreviation
Operation and Maintenance	O&M
Oolite, oolitic	ool
Oomold, oolitic	oom
Open	op
Orange	orng
Organic	org
Othoclase	orth
Outcrop	oc
Oxidized	ox
Part, partly	pt
Parting	ptg
Pearl, pearly	prly
Pebble	pbl
Pebbly	pbly
Pellet	pel
Permeability	perm, K
Petroleum, petroliferous	pet
Phosphate, phosphatic	phos
Pink	pk
Pisolite, pisolitic	piso
Pitted	pit
Plagioclase	plag
Plane	pl
Plastic	plas
Plastic Index	PI
Platy	plty
Polish, polished	pol
Poor, poorly	p
Porcelaneous	porc
Porosity, porous	por
Possible, possibility	pos
Pounds per square inch	lb/in^2
Pounds, per square foot	lb/ft^2
Predominate, predominantly	pred
Preserved, preservation	pres
Primary	prim
Prism, prismatic	pris
Probable, probably	prob
Prominent, prominently	prom

APPENDIX A (continued)

Word	Abbreviation
Pseudo-	psdo
Purple	purp
Pyrite, pyritized	pyr
Pyroclastic	pyrclas
Quartz	qtz
Quartzite	qtzt
Quartzitic	qtzc
Quartzose	qtzs
Radiate, radiating	rad
Range, ranging	rng
Regular	reg
Remnant	rmn
Replaced, replacing, replacement	repl
Reservoir	rsvr
Residue, residual	resd
Resinous	rsns
Rhomb, rhombic	rhmb
Rock	rk
Round, rounded	rd
Rubbly	rbly
Safety Evaluation of Existing Dams	SEED
Safety of Dams	SOD
Sample	spl
Sand	sd
Sandstone	ss
Sandy	sdy
Saturated, saturation	sat
Scattered	scat
Schist, schistose	sch
Secondary, second	sec
Sediment, sedimentary	sed
Selenite	sel
Shale	sh
Shaly	shy
Siderite, sideritic	sid
Silica, siliceous	sil
Siltstone	slts

APPENDIX A (continued)

Word	Abbreviation
Silt	ML or MH
Silty	slty
Slabby	slab
Slickensided	slks
Slight, slightly	sl
Small	s
Smooth	sm
Soft	sft
Solution	sol
Sorted	srtd
Sorting	srtg
Specific gravity	spg
Sphalerite	sphal
Stain, stained, staining	stn
Standard	Std
Stipped	stip
Stone	st
Strata, stratified, stratification	strat
Streak	str
Striated, striations	stri
Stringer	strg
Strong	stg
Structure	struc
Stylolite	stly
Subangular	sbang
Subrounded	sbrd
Sulphur	S
Surface	surf
Tabular	tab
Test pit	TP
Texture	tex
Thick	thk
Thin	thn
Throughout	thru
Tight, tightly	tt
Total depth	TD
Trace	tr
Translucent	trnsl
Transparent	trnsp

APPENDIX A (continued)

Word	Abbreviation
Tuffaceous	tuf
Unconformity	unconf
Unconsolidated	uncons
Upper	up
Variable	var
Varicolored	vcol
Variegated	vgt
Varved	vrvd
Vegetation	veg
Vein	vn
Vertical	vert
Very	v
Vesicular	ves
Vitreous	vit
Volcanics	volc
Vug, vuggy, vugular	vug
Water level	WL
Wavy	wvy
Waxy	wxy
Weak	wk
Weakly	wkly
Weather, weathered	WX
Welded	wld
Well	w
White	wh
Wide, widely	wd
With	w/
Without	w/o
Yellow	yel
Zone	zn

Note: Metric unit abbreviations are provided in the *Metric Manual*.

APPENDIX B
TECHNIQUES FOR PLOTTING GEOLOGIC STRUCTURES

Projecting Surface Features

The approximate surface trace of planar geologic features such as faults, shears, dikes, or geologic contacts can be projected on a topographic-geologic map between two known points or beyond a known point (see fig. B-1) to predict the probable surface location of that feature in terrain where outcrops are obscured by vegetation or surficial deposits. Assumptions must be made that the feature is planar, and due care should be taken that the measured attitude is correct and not affected by surface creep or other structural complications. The more correct the assumptions, the more reliable will be the plotted surface trace.

If you know a surface location of the feature, a true strike and dip, and have a contoured base map, graphic or trigonometric methods may be used to compute the horizontal throw of planar features for a given difference in elevation. A simple and rapid dip projection chart may be used and is

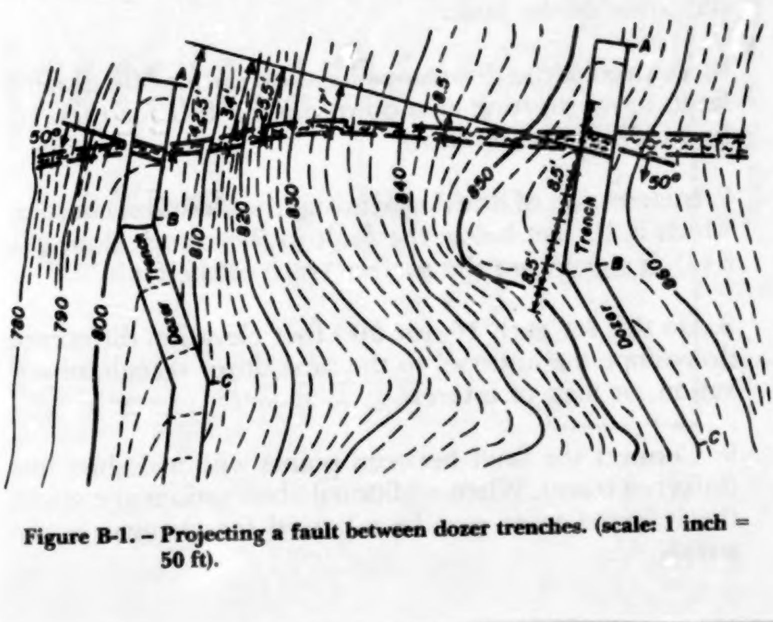


Figure B-1. – Projecting a fault between dozer trenches. (scale: 1 inch = 50 ft).

provided on fig. B-2. A sample problem has been included for explanation.

Techniques Using Dip Projection Chart

This technique applies to projections beyond a trench or other exposure, or for planar geologic features other than a fault.

1. As a general rule, use a 50-foot contour interval for dips steeper than 55°; use a 10-foot contour interval (if available) for flatter dips.

2. From the projection chart, determine the horizontal "throw" of the 50° dip example fault for an evaluation difference of 10 feet.

3. Determine elevation where the fault exposed in the trench floor intersects the natural ground surface (El. 854).

4. Strike off the horizontal "throw" distance (8.5 feet) normal to the strike of the fault in both up dip and down-dip directions.

5. If using a drafting machine, set up the arm parallel to the strike of the fault.

6. To predict the downslope location of this 50° dipping fault, move drafting arm down dip 8.5 feet for each 10-foot elevation difference.

7. Intersection of drafting arm and the elevation contour, which is 10 feet below the fault in the trench floor (El. 844), is a point on the surface trace of the fault.

8. Do this for each 10- (or 50-) foot elevation difference downslope (or upslope) to the next dozer trench, observation, or area of interest.

9. Connect the fault between points with a dashed line (inferred trace). When additional observations are made, the inferred trace may be adjusted for changes in dip strike.

SLOPE	DIP ∡	% GRADE
1:1	45°	100%
1¼:1	38°-40'	80%
1½:1	33°-41'	67%
1¾:1	29°-45'	57%
2:1	26°-34'	50%
2½:1	21°-48'	40%
3:1	18°-26'	33%
4:1	14°-02'	25%
5:1	11°-19'	20%
6:1	9°-28'	17%
7:1	8°-08'	14%

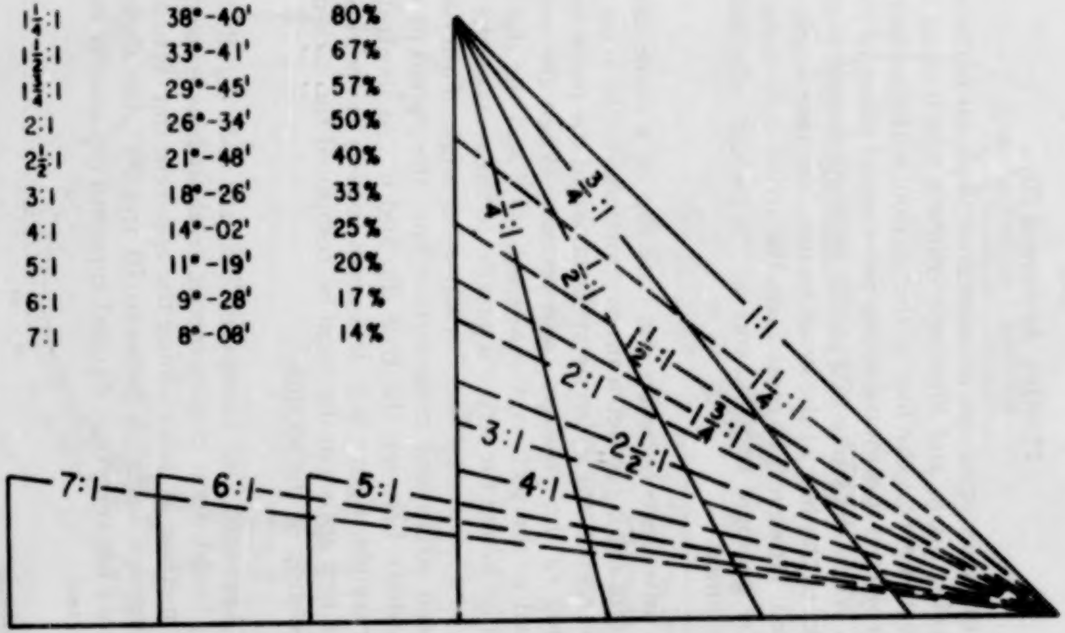


Figure B-2. – Slope angles, dips, and percent grades for slope design.

For exposures with vertical walls, there will appear to be a lack of continuity between the fault in the floor and the surface trace above the trench, depending upon dip of the fault and height of the trench wall.

Plotting Apparent Dips

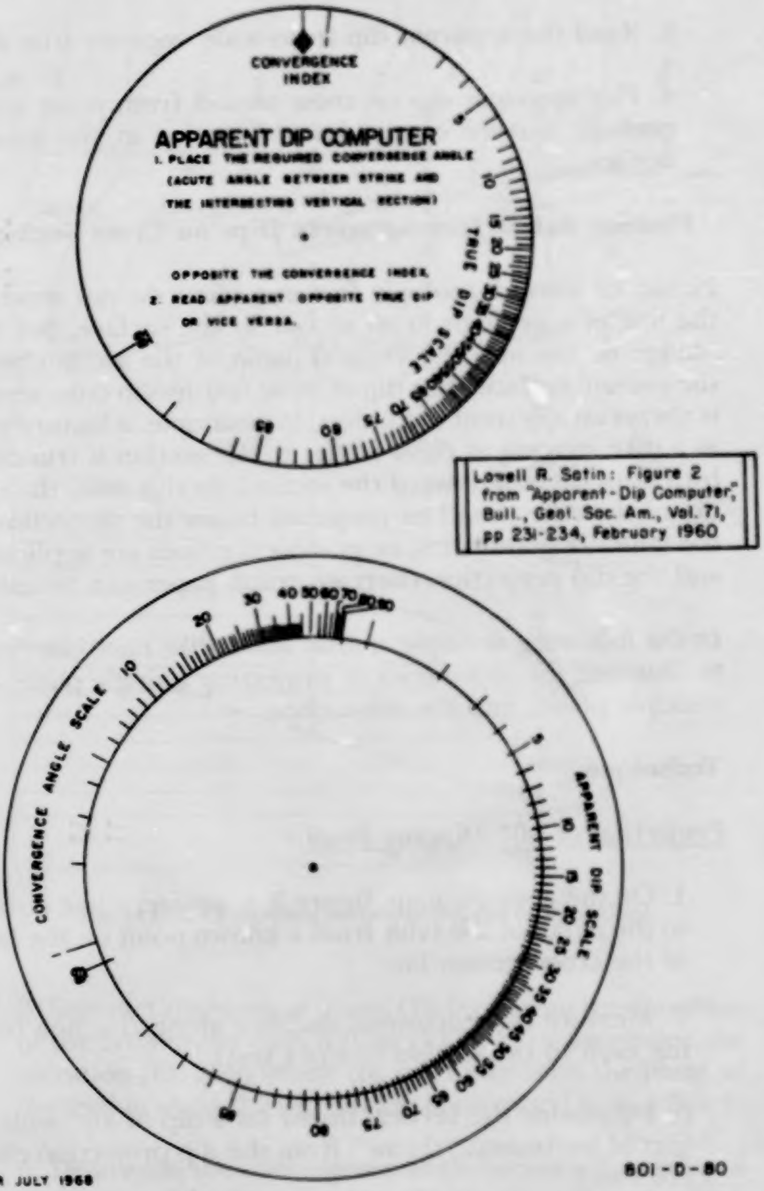
To construct a geologic cross section, all planar features such as faults, dikes, and lithologic contacts which cross or are projected across the line of the section at the surface must be projected downward along the vertical plane of the section. When the strike of a planar geologic feature is at right angles to the line of the cross section, the true angle of dip is used. However, in most cases the strike is at some angle to the geologic section, and an "apparent" dip must be determined.

The difference between the true dip of a plane and the apparent dip is geometrically proportional to the acute angle (convergence angle) between the strike of the plane and the bearing of the geologic cross section. When the strike is normal to the section, the angle is 90°, and the dip is the true dip. When the strike is parallel to the section, the angle is 0°, or a horizontal line. For any other angle of intersection between strike and cross-section line, the apparent dip is somewhere between the true dip and 0°, as illustrated in the example, figure B-2. If a cross section includes a turn line, a new apparent dip must be computed for each different bearing of the section.

An "Apparent Dip Computer," figure B-3, (L. R. Satin, 1959) based upon trigonometric relationships is used as a rapid method of determining the apparent dip. When "the convergence angle" is between 70 and 90°, the slight discrepancy between true dip and apparent dip usually may be neglected.

Technique

1. Measure the acute angle between the strike of the geologic feature and the bearing of the cross section (the strike may have to be projected to the section or mathematically determined).



APPARENT DIP COMPUTER

1. PLACE THE REQUIRED CONVERGENCE ANGLE (ACUTE ANGLE BETWEEN STRIKE AND THE INTERSECTING VERTICAL SECTION) OPPOSITE THE CONVERGENCE INDEX.
2. READ APPARENT OPPOSITE TRUE DIP OR VICE VERSA.

Lowell R. Sotin: Figure 2 from "Apparent-Dip Computer," Bull., Geol. Soc. Am., Vol. 71, pp 231-234, February 1960

USBR JULY 1968

801-D-80

Figure B-3. – Apparent dip computer.

2. Set the "convergence index" pointer to the Apparent Dip Computer opposite this "convergence" angle.

3. Read the apparent dip from scale opposite true dip.

4. Plot apparent dip on cross section from point where geologic feature crosses line of section at the ground surface.

Plotting Subsurface Apparent Dips on Cross Sections

Planar or curved geologic features often do not intersect the line of a geologic cross section at the surface, but may plunge or dip into the vertical plane of the section below the ground surface. The dip of these features in cross section is always an apparent dip unless, for example, a feature such as a dike striking at right angles to the section is truncated by a fault dipping toward the section. In this case, the true dip of the dike would be projected below the projection of the fault. Trigonometric or graphic methods are applicable, and the dip projection chart or graph paper can be used.

In the following example, a fault and a dike have been used to illustrate the techniques or projecting a single plane and multiple planes into the subsurface.

Technique

Projection of 40° Dipping Fault

1. On the geologic map, figure B-4, project a line normal to the strike of the fault from a known point on the fault to the cross section line.

2. Measure the horizontal distance along this line from the fault to the section line (84 feet).

3. Determine the vertical throw for a dip of 40° with 84 feet of horizontal "throw" from the dip projection chart (70 feet).

4. Drop a vertical line down through the cross section from the point where this normal line hits the cross section.

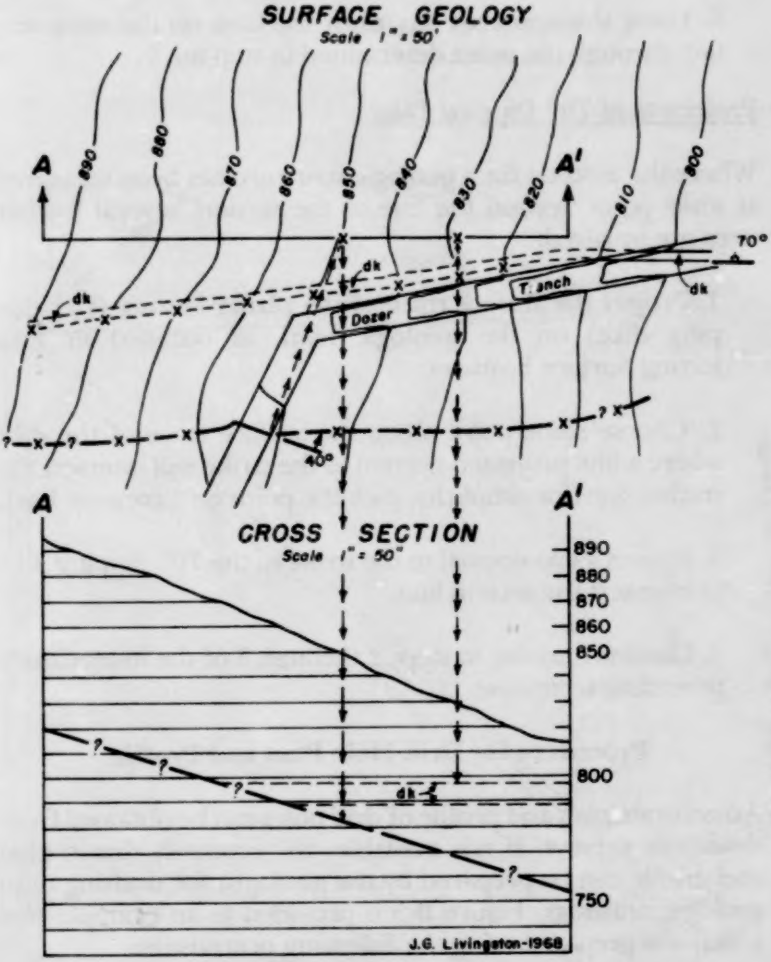


Figure B-4. – Projecting surface geology to cross sections.

5. Subtract the vertical throw (70 feet) from the elevation of the fault in the trench floor (El. 852) to determine the elevation (El. 782) where the fault intersects the plane of the section along the vertical line constructed in step No. 4.

6. Determine the convergence angle between the strike of the fault and the line of section (21°).

7. Compute the apparent dip for the 40° fault (17°; see technique for plotting apparent dips).

8. Using this apparent dip, draw the fault on the cross section through the point determined in step no. 5.

Projection of 70° Dipping Dike

Where the attitude for a geologic structure has been measured at some point beyond the line of the section, several further steps are involved:

1. Project the surface trace of the planar feature (70° dipping dike) on the geologic map, as outlined in Projecting Surface Features.

2. Choose some point along the surface trace of the dike where a line projected normal to the strike will intersect the section line (for simplicity, pick the point on a contour line).

3. Project a line normal to the strike of the 70° dipping dike to intersect the section line.

4. Continue similar to steps 2 through 8 of the immediately preceding technique.

Procedure for Drill Hole Plan and Profile

An accurate plan and profile of drill holes can be obtained from downhole surveys. If not available, an accurately drawn plan and profile can be prepared by the geologist for drafting onto geologic drawings. Figure B-5 is provided as an example plot which was prepared using the following procedures:

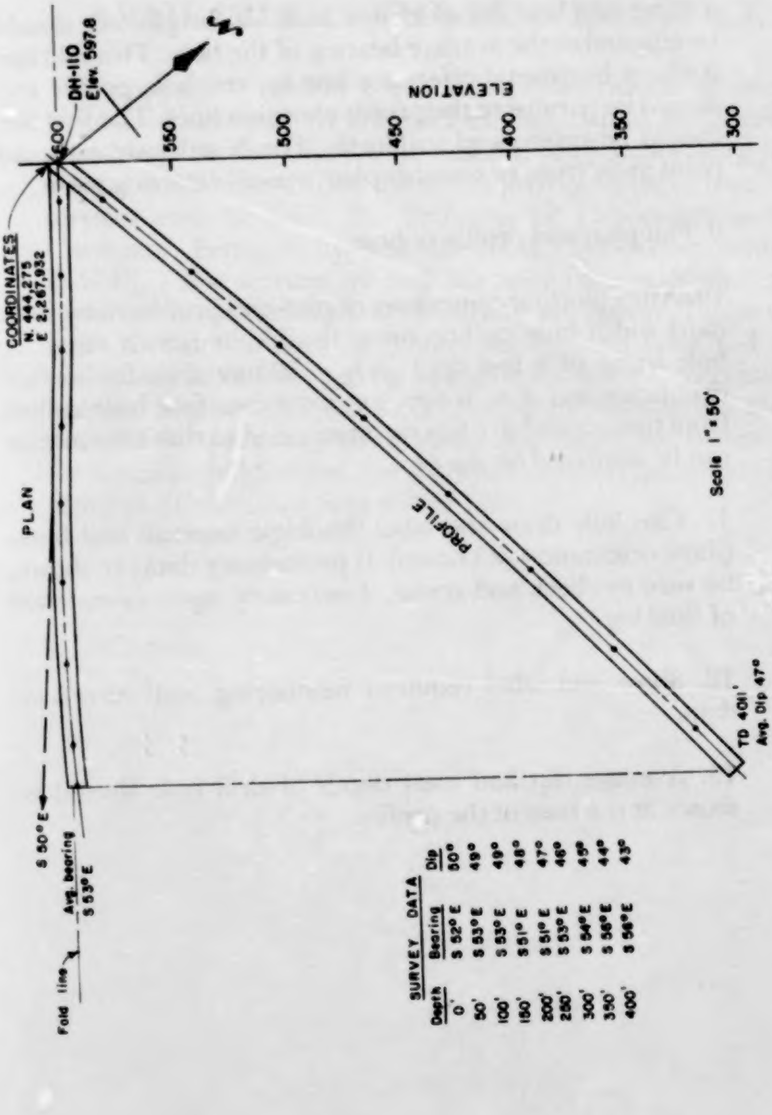
1. Plot with a drafting arm, preferably mounted with an appropriate scale for drawings being used.

2. Use 8- by 11-inch Clearprint "fade out" graph sheets.

3. Prominently display the drill hole number and geologist's name.

4. Plot drill hole profile as if looking downstream.

5. First, set up the profile scale (vertical so that 50-foot elevations agree with the heavy graph lines). Then locate profile starting point with references to these elevation lines.



SURVEY DATA

Depth	Bearing	Dip
0'	S 52° E	50°
50'	S 53° E	49°
100'	S 53° E	49°
150'	S 51° E	48°
200'	S 51° E	47°
250'	S 53° E	46°
300'	S 54° E	45°
350'	S 56° E	44°
400'	S 56° E	43°

Figure B-5. – Drill hole plan and profile.

6. Survey readings (bearings or inclinations) should be extended one-half of the distance between points of survey.

7. Starting point of plan view should be common to starting point of profile.

8. The fold line, on which the plan will be plotted, should be equated to the average bearing of the hole. This fold line is also a horizontal reference line for the hole profile and should be parallel to the profile elevation lines. The fold line should be referenced to North. The North arrow should point away from or towards plan—profile starting point.

9. Plot plan and profile of hole.

10. After plotting centerlines of plan and profile, draw standard width hole outline using flexible or french curve. A hole width of 8 feet on 1 inch = 50-foot scale for surface drill holes and 4 or 6 feet for any subsurface hole drilled from tunnels and drifts is recommended so that information can be displayed on the plot.

11. Carefully draw and label lithologic intervals and faults (show orientation, if known). If preliminary data are shown, be sure to check and revise, if necessary, upon completion of final log.

12. Show and label required weathering and water-level data.

13. Average dip and total depth of drill hole should be shown at the base of the profile.

APPENDIX C

PETROGRAPHIC, SOIL, AND ROCK MECHANICS TESTS AND SERVICES AVAILABLE AT THE DENVER OFFICE

This appendix provides a generalized description of petrographic services and soil and rock mechanics tests and services available from the Division of Research and Laboratory Services at the Denver Office. Table C-1 provides a list of tests and services available from the Petrographic Laboratory in the Chemistry, Petrography, and Chemical Engineering Section, D-3743. These services are available upon request. Sample size applications/capabilities and limitations are shown. Tables C-2 and C-3 describe rock mechanics testing, and table C-4 describes soil laboratory testing available from the Geotechnical Services Branch, Soil and Rock Testing Sections. For a more detailed discussion of Petrographic capabilities, see Bureau of Reclamation publication: *Petrographic Laboratory Analytical Techniques and Capabilities,* September 1985.

Table C-1. – Denver Office petrographic laboratory analyses.

Type of analyses	Sample size	Applications/capabilities	Limitations
Rock classification	Representative rock sample	Technical description and classification including mineralogical composition and estimated volume percentages.	Can only describe and classify, rock submitted. Cannot replace, predict, or extrapolate physical properties test results.
Afterbreak examination	Determined by size of physical properties test specimens	Describes mode of failure of test specimen; defines actual strength of rock or strength of structural features, and sometimes, fracture and joint systems based on mineralogical composition of coating and fillings. Defines mineralogical composition of failure surfaces.	Failure is typically dependent upon orientation of structural features with respect to orientation of test specimen. Failure and strength cannot be predicted or extrapolated for untested specimen.

Table C-1. – Denver Office petrographic laboratory analyses.—Continued

Type of analyses	Sample size	Applications/capabilities	Limitations
Wetting test	N-size core or about 4 cubic inches of representative sample preferred	Documents and shows photographic evidence of physical changes resulting from immersion in Denver tapwater. Aids in determining potential for and rate of deterioration, type of support required, period of time before support is required, and method of most desirable excavation.	Cannot replace, predict, or extrapolate uplift expansion, or free-swell test results. Cannot determine mineralogical composition.
Free-swell test	Representative, about fist-size sample	Qualitative test which indicates amount of unconfined volume change of a smectite (montmorillonite) clay to to wetting	Cannot replace, predict, or extrapolate uplift or expansion test results. Does not identify type or amount of smectite (montmorillonite) present.

Table C-1. – Denver Office petrographic laboratory analyses.—Continued

Type of analyses	Sample size	Applications/capabilities	Limitations
Riprap[1]	Rock sample of 600 pounds minimum. See USBR *Earth Manual* Designation E-39	Rock classification and freeze-thaw durability. Supplements concrete laboratory physical properties results.	Cannot determine maximum size of rock available, can only classify and evaluate rock submitted.
Rockfill[1]		Analyzed and tested using riprap criteria.	
Soil	About 1 pint of representative sample preferred	Identification of mineralogical composition and percentages, water-soluble minerals, and expansive smectite (montmorillonite). Provides wetting, drying, and expansive characteristics. Aids in determining occurrence and origin of material properties test results.	Cannot replace, predict, or extrapolate soils laboratory physical properties test results.

Table C-1. – Denver Office petrographic laboratory analyses.—Continued

Type of analyses	Sample size	Applications/capabilities	Limitations
Harden Concrete	Representative sample: 4-inch diameter core is minimum size. See ASTM C42, C457 and C856	Describes aggregate rock types and physical and chemical quality, composition, and condition of paste, air-void system, secondary and hydration products and fracture system. Analysis of afterbreak specimens to define strength and describe mode of failure. Evaluates air-void parameters, condition of the concrete, and workmanship; and determines cause and extent of inferior quality, distress, and/or deterioration.	Cannot determine original concrete-mix design, type or amount of chemical admixtures, cement type, or cement content. Cannot replace, predict, or extrapolate concrete laboratory physical properties test results.

Table C-1. – Denver Office petrographic laboratory analyses.—Continued

Type of analyses	Sample size	Applications/capabilities	Limitations
Grout	Representative sample	Evaluates cause of failure to properly set. Identifies mineralogical set retarders and accelerators. Determines presence or absence and cause of deterioration.	Cannot determine original grout mix design, type or amount of chemical admixtures, cement type, or cement content.
Concrete aggregate [1]	See USBR *Concrete Manual,* Designation 7, or ASTM C295	Aids in the interpretation of physical and chemical quality. Supplements concrete laboratory physical properties test results.	Cannot replace, predict, or extrapolate concrete laboratory physical properties test results.

Table C-1. – Denver Office petrographic laboratory analyses.—Continued

Type of analyses	Sample size	Applications/capabilities	Limitations
X-ray diffraction	About 1 heaping teaspoon of representative sample *preferred*	Identifies crystalline compounds and estimated volume percentages of rock, *minerals, soil, concrete,* pozzolan, grout, stains, seals or coatings, paint pigments, sludge, filtrates, organics, corrosion products, metals and alloys.	Cannot identify noncrystalline (amorphous) materials or liquids; cannot determine structure, texture, or fabric of materials; and cannot identify physical properties of materials.
X-ray flourescence spectroscopy	About 1 heaping teaspoon of representative sample preferred	Identifies crystalline composition and relative amounts, and qualitative elemental identification chiefly to aid chemistry laboratory in elemental analyses.	Cannot identify compounds or detect elements below atomic No. 12 (magnesium) or above atomic No. 92 (uranium).

Note: Statement or problem and/or purpose of the analyses, sample identification, and location should be included when submitting samples for petrographic analyses.

[1] Samples should be submitted to Chemistry, Petrography, and Chemical Engineering Section, D–3743.

Table C-2. – Denver Office rock mechanics laboratory tests.—Continued

Type of tests	Sample size and apparatus	Testing apparatus	Applicable output/results	Approximate cost per single specimen or sample*
Comprehension tests				
Uniaxial	Any size core—limited by capacity of preparation equipment	Servo-controlled load and strain. Instrumentation consists of strain gauges, deformation jacket, and deflectometer; strain gauges unlimited; DFC-limited stress levels (currently).	Static compressive strength Young's Modulus Poisson's ratio	Compressive strength—$15 to $25; Compressive strength/modulus—$25 to $30.
Triaxial	N-size core only	Servo-controlled principle load; triaxial chamber manually held constant. Instrumentation consists of strain gauges and deflectometer.	Static triaxial compressive strength Young's modulus Poisson's ratio Triaxial shear	Triaxial strength only—$50 to 455; triaxial strength-/modulus—$75 to $80; triaxial shear—$100
Tension tests				
Indirect/ Brazilian	Any size core	Load plattens with curved jaws for N-size core, flat for all other sizes. Servo-controlled strain and stress. Instrumentation—strain gauges and deflectometer.	Tensile strength Tensile strength vs. strain	Tensile strength—$10; strength vs. strain—$15.

*1988 Costs

Table C-2. – Denver Office rock mechanics laboratory tests.—Continued

Type of tests	Sample size and apparatus	Testing apparatus	Applicable output/results	Approximate cost per single specimen or sample*
Shear strength tests				
Direct shear (open joints or breaks-bond)	Core up to 10 inches (250 mm) diameter	Manually controlled normal and shear loads on predefined plane. Instrumentation for horizontal displacement only; load cells for normal load and horizontal (shear) load.	Peak shear strength vs. displacement Residual shear strength vs. displacement Coefficent of sliding friction Breakbond or intact shear strength	Shear strength (any)—$150 to $300. Coefficient to sliding friction—$650 to $800.
Tilt table	Six-inch (150-mm) core or smaller	Crudely constructed portable and manually operated tilt table.	Sliding shear strength Coefficient of sliding friction	Sliding friction strength—$35. Coefficient of sliding friction—$75.
Triaxial shear		— See triaxial compression tests —		

*1988 Costs

Table C-2. – Denver Office rock mechanics laboratory tests.—Continued

Type of tests	Sample size and apparatus	Testing apparatus	Applicable output/results	Approximate cost per single specimen or sample*
Swelling—expansion tests				
Uplift	N-size core	Manually controlled with gravity weights; mechanical dial gauge.	Pressure vs. zero displacement Pressure vs. time	Depends on length of tests—$40 to $70.
Expansion	N-size core	Manually controlled with gravity weights; mechanical dial gauge.	Fixed pressure vs. displacement Pressure vs. time Pressure to return to zero displacement	Depends on length of tests—$40 to $70.
Intrinsic properties				
	Any size core or lump samples	Test procedure destroys in situ water content.	Water content	$4 to $9.
		Sample may be destroyed for true porosity values.	Apparent porosity	$7 to $12.
			Bulk density	$5 to $8.

*1988 Costs

Table C-2. – Denver Office rock mechanics laboratory tests.

Type of tests	Sample size and apparatus	Testing apparatus	Applicable output/results	Approximate cost per single specimen or sample*
Nondestructive tests				
Ultrasonics	Any size core or "cutable" lump samples	Tests can be performed along any direction with pulse generator and oscilloscope; uses compression and shear transducers.	Young's modulus Poisson's ratio Bulk modulus Shear modulus Lane's constant Prosity Shear-wave velocity Compressional wave velocity	Depends on whether specimen preparation costs are included in another test; usually $16 to $24.
Microseismics SAR (subaudible rock noise)	Laboratory or field application for slope stability or microseismic events	Battery-powered, portable apparatus	Number of events vs. time source of microseismic events. Prediction tool for stability of rock masses.	Costs and time vary greatly with installation and objectives.

*1988 Costs

Table C-3. – Denver Office rock mechanics field tests/services.

Types of tests	Preparation, apparatus, limitations, and notes	Applicable output/results	Approxmiate cost per test
Jacking/deformation test			
Uniaxial jacking	Expensive preparation and time-consuming testing, 10 to 15 days per test. Requires drift or adit and minimum 5- by 7-ft (1.52- by 2.13-m) chamber with 60-in^2 (0.09-m^2) prepared surface; two 20- to 30-ft (6- to 9-m) deep drill holes, logging and mapping. Loading applied cyclically in 200 ± 1 lb/in^2 (14 ± kg/cm^2) increments up to 1,000 lb/in^2 (70kg/cm^2) in two directions with 35-in (890-mm) diameter jacks. Instrumentation with multiple strain gauges and digital readout equipment.	Tests obtain in situ deformation modulus, permanent set, rebound, and creep of rock mass with discontinuities.	Varies
Radial jacking	Very expensive preparation and time consuming, 10- to 15-day test duration. Requires minimum 8.5-ft-diameter by 8-ft-long (2.6-m-diameter by 2.4-m-long) chamber, prepared surface; 16 or more drill holes 30 ± ft (9 ± m) deep geologic mapping and logging. Cyclic loads applied along full periphery. Uses large flat jacks, multiple strain gauges, and digital readout equipment.	Tests obtain in situ deformation modulus, permanent set, rebound, and creep of rock mass.	Varies

Table C-3. – Denver Office rock mechanics field tests/services.—Continued

Types of tests	Preparation, apparatus, limitations, and notes	Applicable output/results	Approxmiate cost per test
Gouge plate jacking	Requires 7- by 7- by 10.5-ft (2.1-by 2.1- by 3.2-m) test chamber excavated to approx. 18± in (460±mm) from discontinuity to be tested [distances of 1 to 5 ft (0.3 to 1.2 m) acceptable]. Large diameter drill hole 10- to 18-in (254- to 457-mm) diameter required for bearing plates. Generally, pressures applied cyclically in 50-lb/in² (3.5-kg/cm²) increments.	Tests obtain permanent set and rebound.	Varies
In situ stress tests			
Direct shear (internal shear resistance – in situ shear)	Requires test 7- by 7- by 10.5-ft (2.1- by 2.1-by 3.2-m) test chamber, one side of which is parallel to discontinuity to be tested, leaving 8±in (200±mm) intact rock above discontinuity. Diamond saw cuts to produce 18±in (460±mm) block. Equipment includes spherical bearing blocks, column segments, and hydraulic jacks.	Sliding friction. Shear resistance along existing discontinuities. Block is moved several times with additional normal loads applied.	Varies

Table C-4. – Denver Office soil laboratory tests.

Type of test	Sample size and preparation	Applicable output/results	Approximate cost per test
Physical properties			
Gradation analysis Hydrometer Bottom withdrawal	Dependent on maximum particle size, see USBR 5325	Soil classification, engineering properties	$80 to $300
Atterberg limits Liquid limit Plastic limit Shrinkage limit	0.89 kg (2 lb)	Soil classification, engineering properties	$200
Specific gravity + No. 4 sieve size – No. 4 sieve size	0.2 to 2.5 kg (0.5 to 5 lb)	Use in various soil phase calculations	$200
Water content	0.1 to 0.5 kg (0.2 to 1.2 lb)	Use in various soil phase calculations	$20
Unit weight determination	Various undisturbed	Engineering properties	$20
Clay dispersivity Double hydrometer Crumb Pinhole	2.5 to 3.0 kg (5.5 to 7 lb)	Clay dispersive characteristics, engineering properties	$250

Table C-4. – Denver Office soil laboratory tests.—Continued

Type of test	Sample size and preparation	Applicable output/results	Approximate cost per test
Laboratory compaction			
USBR (standard)	20 kg (45 lb)	Moisture unit weight relationship	$100 to $1000
ASTM (modified)	20 kg (45 lb)		
Harvard	2 kg (5 lb)		
Large scale	Varies		
Maximum index unit weight	Varies		
Minimum index unit weight	Varies		
Permeability testing	0.5 to 60 kg (1.2 to 130 lb)	Coefficient of permeability	$500 to $1500
Standard 8"			
Large scale 20"			
Back pressure 3.25"			
Filter testing	10 to 60 kg (22 to 130 lb)	Filter performance	$500 to $1500
6" dia.			
12" dia.			
Consolidation	0.3 to 0.5 kg (0.7 to 1.2 lb)	Consolidation-settlement/time consolidation Collapse preconsolidation Expansion chracteristics Uplift pressure	$700 to $1000
Consolidation test			
Uplift			
Expansion			

Table C-4. – Denver Office soil laboratory tests.—Continued

Type of test	Sample size and preparation	Applicable output/results	Approximate cost per test
Strength testing			
Unconfined compression	0.3 kg (0.7 lb)	Shear strength, stress-strain	$200
Direct shear	0.3 to 1 kg (0.7 to 2.2 lb)	Shear strength, stress-strain	$500
Repeated direct shear	0.3 to 1 kg (0.7 to 2.2 lb)	Shear strength, stress-strain	$800 to $1500
Rotational shear	0.1 to 1 kg (0.2 to 2.2 lb)	Residual shear strength	$500
Triaxial shear UU, CU, CD, & Multistage	0.1 to 1 kg (0.2 to 2.2 lb)	Shear strength, stress-strain, volume change, pore pressure	$1000 to $2000
Nondestructive testing			
Radiography	Tube samples or test specimens	Determine quality, gravel content, density variation	$20
Dynamic testing			
Cyclic triaxial	0.2 to 2 kg	Liquefaction, physical properties, and modulus damping	$3000 to $5000
Resonant column	0.2 to 15 kg	Physical properties and modulus damping	$2000 to $5000
Soil additives			
Cement Fly ash Lime	Varies	Strength, durability, percent content, unit weight	Varies

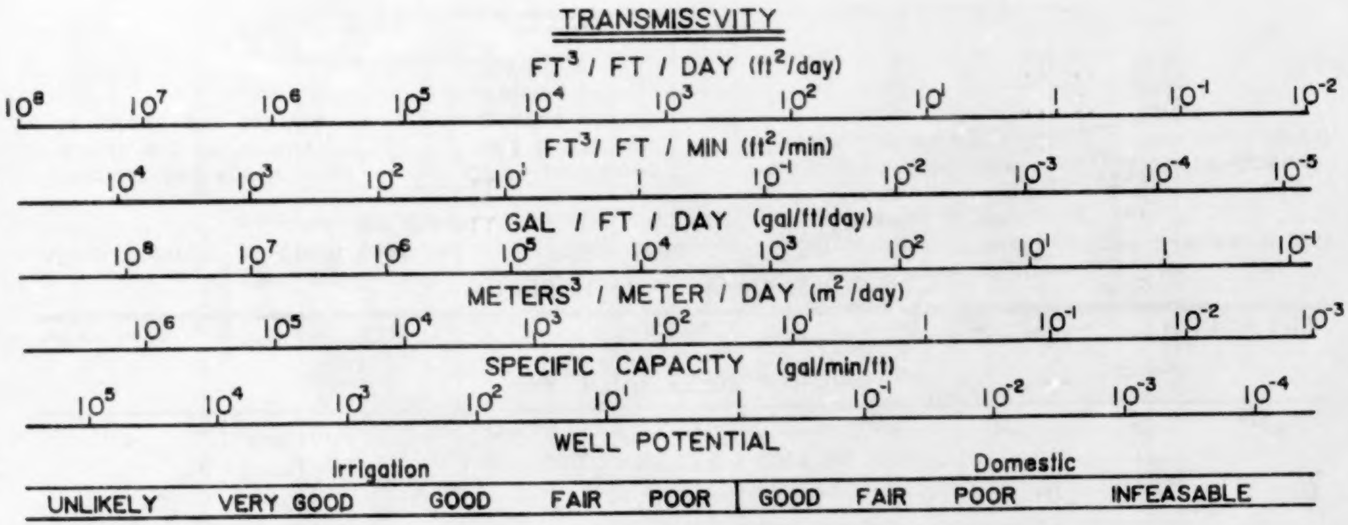
APPENDIX D

MISCELLANEOUS EMPIRICAL DATA

GENERAL ROCK BOLT CHART

TYPE		SIZES AVAILABLE	APPLICATIONS (ROCK & EXCAVATION TYPE)	ADVANTAGES	DISADVANTAGES	INSTALLATION EQUIPMENT	COMMENTS
TENSIONED REINFORCEMENT							
Mechanical Expansion Anchor	Solid Rebar Rock Bolts	1/2" to 2" (larger sizes available if needed)	Bolting in moderately hard to hard rock	Widely available, requires no special tools	Anchor may not hold in weaker rocks, subject to some corrosion unless grouted	No special equipment required	
	High Tensile Rock Bolts	1/2" to 2" diameter	Bolting in moderately hard to hard rock	May reduce the number of bolts required to stabilize area	Expensive, anchor may not hold in weaker rocks, subject to some corrosion unless grouted	No special equipment required	
	Hollow Groutable Rock Bolts	1" to 2" diameter	Bolting in moderately soft to hard rocks, used where bolt may be subject to corrosion	Relatively easy to grout, assures full length grouting of bolt	Diameters smaller than 1" generally not available	Grout pumps and correct fittings	
Slot and Wedge Bolts		1/2" to 2" diameter	Used primarily in underground excavations where high strength is not required	Rapid installation	Poor holding characteristics, anchorage not assured	No special equipment required	Rarely used, generally not available
Perfobolt Anchors		3/4" diameter	Used in lieu of other types of fully grouted bolts and dowels	Fairly good corrosion protection, fairly rapid installation	Requires external mixing of cement grout and hand trowelling of cement into perforated sleeve	No special equipment required	
Grouted Dowels		1/2" to 2" (larger sizes available if needed)	Used where corrosion protection is required, may also be used in weaker rock than mechanical expansion anchor type	Fairly good corrosion protection, may be used in weaker rock than mechanical anchors	Somewhat difficult to install grout in vertical-up holes	Grout pumps and correct fittings	
Cable Anchors		3/4" to 52,1/2" strands	Used in high load situations or where space limitations do not allow handling of long rigid bolts	Able to hold very high loads, very long lengths may be fabricated, may be installed in soils if properly grouted	Expensive, require careful installation	Grout pump, hydraulic tensioner	
Resin Grouted Anchors		1/2" to 1 3/4" (#14 rebar) Resin Cartridges 1 1/16" to 1 15/16"	May be used in lieu of cement grouted bolts or used in rock too soft to be bolted with mechanical anchors	Rapid installation, variable set times available.	Sensitive to temperature, unused resin deteriorates with age	No special equipment	
UNTENSIONED REINFORCEMENT							
Resin Grouted Anchors		1/2" to 1 3/4" (#14 rebar) Resin Cartridges 1 1/16" to 1 15/16"	May be used in lieu of cement grouted bolts or used in rock too soft to be bolted with mechanical anchors	Rapid installation, variable set times available	Sensitive to temperature, unused resin deteriorates with age	No special equipment	
Split Set Anchors		1 1/2" diameter Lengths to 12 ft.	May be used in rock too soft for other types of bolts and anchors	Rapid installation, may be used in rock too weak for other types of anchors	Hole must be drilled to close diameter tolerances, susceptible to corrosion, not tensionable	Special driver attachment for jackhammer or jacking drill	
Swellex Rock Anchors		1 1/4" expanded Lengths 2–12 ft.	May be used in fairly soft rock, presently used primarily in underground excavations	Rapid installation, may be used in rock too weak for other types of anchors	Requires special installation equipment, not tensionable	Needs water pump and wand to inflate	
Grouted Dowels		3/4" to 2" (larger sizes available if needed)	Used where corrosion protection is required, may also be used in weaker rock and yielding support systems	Fairly good corrosion protection, may be used in weaker rock than mechanical anchors	Somewhat difficult to install grout in vertical-up holes	Grout pump	
Wooden Dowels		Fabricated as needed	Rarely used in engineering practice	Inexpensive, easy to install	Strength not acceptable, not reliable		

Figure D-1. – General rock bolt chart.



NOTES: Transmissivity (T)=KM where

K= Permeability
M= Saturated thickness of the aquifier

Specific capacity values based on pumping period of approximately 8-hours but are otherwise generalized.

Figure D-2. – Comparison of transmissivity, specific capacity, and well potential.

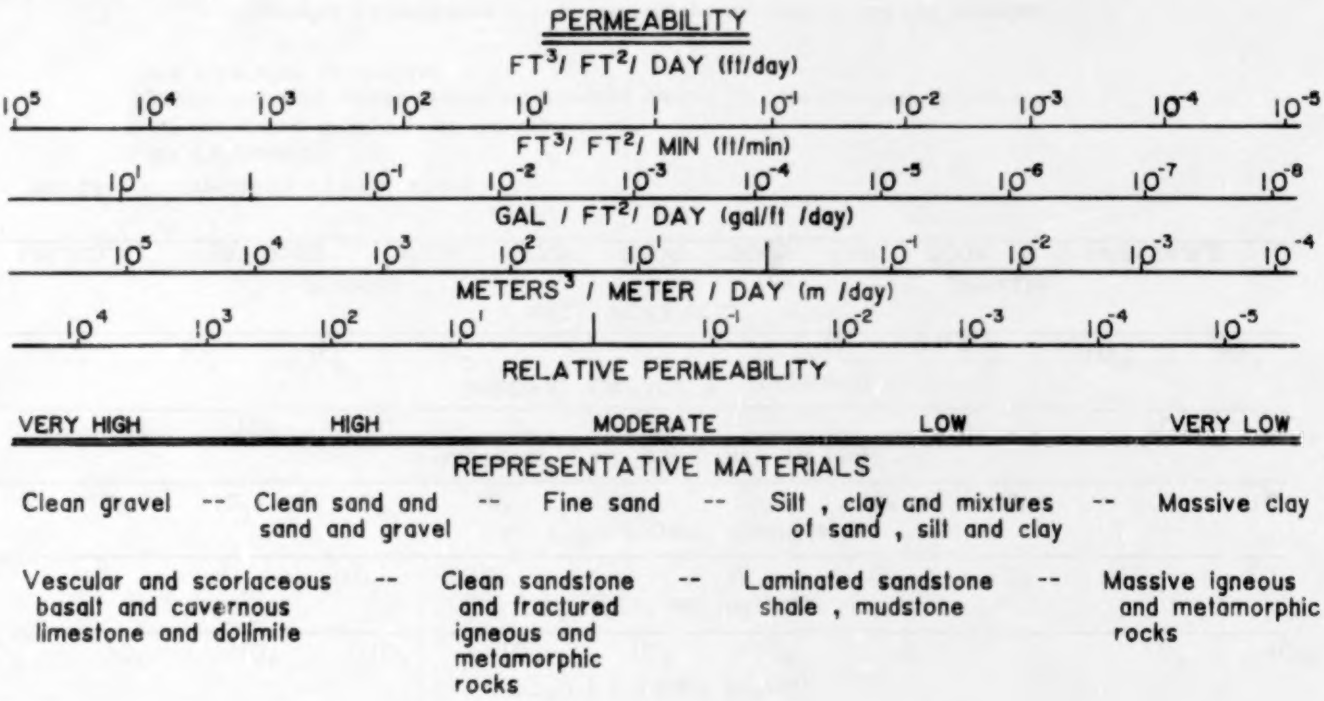
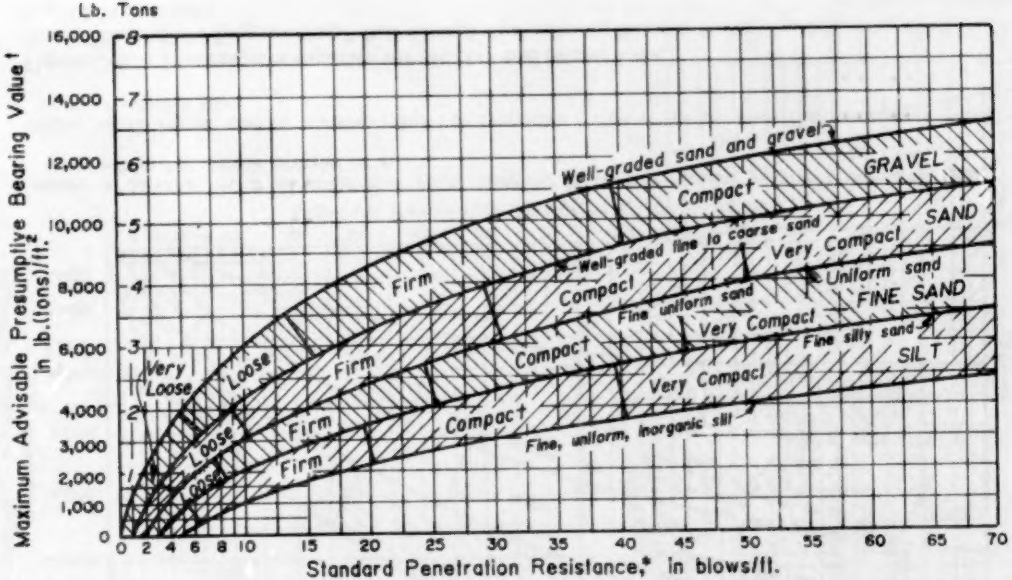


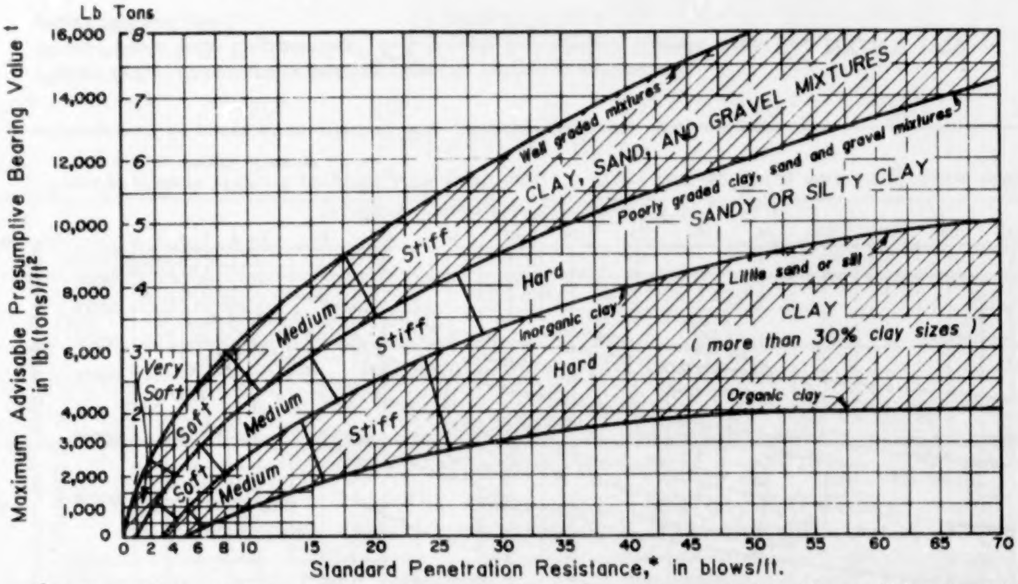
Figure D-3. – Comparison of permeability and representative aquifer materials.



* Number of blows of 140-lb pin-guided drive weight falling 30 in. per blow required to drive a split- barrel spoon with a 2 in. outside diameter 12 in.

†Values must be corrected for effect of weak substrata, high ground water, and surcharge.

Figure D-4. – Presumptive bearing capacity values, granular soils.
(from "Basic Soils Engineering." B.K Hough 2nd edition; Ronald Press Co., NY, NY, 1969.—pages 308 and 309.)



*Number of blows of 140-lb pin-guided drive weight falling 30 in. per blow required to drive a split-barrel sample spoon with a 2-in. outside diameter 12 in.

†Higher values may be used for precompressed (or compacted) clays of low sensitivity than for normally loaded or extra-sensitive clays.

Figure D-5. – Presumptive capacity values, clay and mixed soils.
(from "Basic Soils Engineering." B.K Hough 2nd edition; Ronald Press Co., NY, NY, 1969.—pages 308 and 309.)

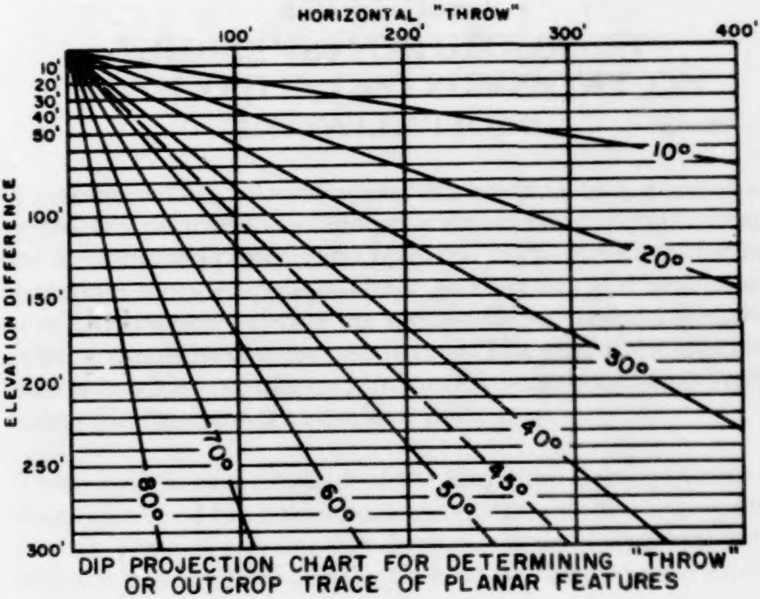


Figure D-6. – Dip projection chart.

APPENDIX E
GUIDELINES FOR GEOLOGISTS INVOLVED IN INSTRUMENTATION INSTALLATIONS

These guidelines provide useful information to Reclamation geologists performing common instrumentation installations for Reclamation projects and features. These guidelines for installations include open-standpipe piezometers and inclinometers. Observation wells are not specifically addressed due to the relative simplicity of these installations. The goal of these guidelines is to achieve satisfactory instrumentation installation in the most efficient manner at the least cost.

These guidelines are a result of the May 1986 Geology Conference. The need for guidelines was evident, and the timing was critical. The *Embankment Dam Instrumentation Manual* was published in January 1987 and the Ground Behavior Measurement chapter for this manual was in preparation; consequently, an immediate document is needed to partially cover the subject.

General

To obtain instrumentation materials and equipment for Reclamation personnel making instrumentation installations contact the Structural Behavior personnel. They will furnish porous-tube piezometers, slotted-pipe and standpipes for observation wells and open-standpipe piezometer installations; inclinometer casing; pneumatic equipment and instruments; vibrating-wire equipment and instruments; and other items. A centralized supply helps to standardize instrumentation installation. Generally these materials and equipment are paid for with SEED monies, and are available to the regions without charge. Contact Mr. Dan Goins at least 2 weeks prior to your need at the site and request the quantities required. If large quantities of vibrating-wire or pneumatic instruments are required, please allow as much lead time as possible.

A geologist should be present during drilling of holes in which instruments are to be installed. Accurate and detailed drill logs can then be prepared for the hole (for use in future interpretation of instrument data). Based upon what is revealed during the drilling, piezometers can be installed at the most appropriate elevations in the holes.

Prior to deviating from Denver Office installation details that are provided for any instruments, contact the principal designer and the Structural Behavior and Instrumentation Section, D-3621. Some well-meaning deviations in the past have compromised installations and resulted in instruments providing little or no valid data.

It is important that the Structural Behavior staff receives the information for instrumentation installations promptly so these data can be processed and properly interpreted. Instrument installation elevations, ground surface elevations, top of standpipe elevations (for open-standpipe piezometers or observation wells), top of casing elevations (for inclinometers), and preliminary or draft drill logs should be sent in promptly. Final drill logs should be sent in upon completion. Drill logs should be unambiguous concerning the ground surface elevations (since the measurement point for depths to the various features generally is not the ground surface).

The Structural Behavior staff is always available for advice or assistance, concerning any instrumentation installations being performed by or for Reclamation.

Instrumentation Installations in Drill Holes

Inclinometer Installations in Drill Holes

The minimum drill hole size required is 6-inch- (152 millimeters) diameter. Where drill holes are larger than 8 inches (203 millimeters) in diameter, devices should be attached to the inclinometer casing approximately every 50 feet (15 meters) to center it in the drill hole.

The type of inclinometer casing used requires careful consideration in light of the specific circumstances of the installation. Substitution of different inclinometer casing should not be done without first consulting the Structural Behavior staff.

Piezometer Installations in Drill Holes

Minimum drill hole size requirements are as follows:

Total depth of drill hole	One piezometer to be installed in hole	Two piezometers to be installed in hole
0- 50 feet (0-15 m)	3-inch-diameter (75 mm)	4-inch diameter (100 mm)
50-150 feet (15-45 m)	4-inch-diameter (100 mm)	4-inch-diameter (100 mm)
150-300 feet (45-91 m)	4-inch-diameter (100 mm)	6-inch-diameter (152 mm)
over 300 feet (91 m)	Determined on case-by-case basis by geology and the Structural Behavior staff.	

The above guidelines may be relaxed in certain favorable situations upon consultation with the Structural Behavior staff.

Installing more than two piezometers in one drill hole should not be attempted, unless there are very compelling reasons. Just as with the above minimum drill hole size requirements, it is possible to violate this requirement and seemingly get away with it. However, resulting data from such an installation have proven to be poor. The inability to make adequate bentonite seals and other problems frequently result in unreliable data and do not accurately represent the actual situation. Such data, which often are discovered only upon very close examination, represents a very bad situation in terms of monitoring and assessing the performances of a dam. Many times in the past, violations of the stated guidelines have led to significant problems developing during the installations. It would have been faster and cheaper (not to mention better) to drill an additional hole and install the shallower piezometer, rather than to jam all the instruments into one suspect installation.

In numbering drill holes that potentially could be completed with instrumentation installations, it would be preferred that "A" and "B" designations be avoided for companion holes (e.g., DH-101, DH-101A, DH-101B). The convention in piezometer identification is to use the drill hole number along with an "A" for the deepest installation and a "B" for the shallowest installation (e.g., PTP-101A and PTP-101B for peizometers in DH-101). This convention becomes confusing when a drill hole has an "A" or "B" suffix. This can be handled, but it is an unnecessary additional source of potential confusion.

Acceptable drilling fluid for drill holes where piezometers will be installed are clean water, biodegradable drill mud (Revert), air, or air foam. Ordinary drilling muds will decrease the permeability of the walls.

Drill holes should be bailed completely dry immediately prior to the commencement of piezometer installation work. In some instances, artesian pressures or other circumstances may make this impossible, but where possible, this should be done because better installations are achieved and because valid data generally can be obtained earlier.

Grout or concrete can be placed in drill holes only after the upper bentonite seal of the upper piezometer has been completed. Otherwise such materials can foul the drill hole wall in the vicinity of the piezometer and potentially affect (negate) data obtained.

In many instances, it is useful to test newly installed piezometers by adding 10 to 20 feet of water into the standpipe, or removing 10 to 20 feet of water from the standpipe, and monitoring the dissipation of the pressure imbalance. Where two piezometers are installed in one hole, both piezometers should be monitored, but only one is "charged" at a time. In this way, it can be determined if the bentonite seals between the piezometers are effective and satisfactory.

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-7923A, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.